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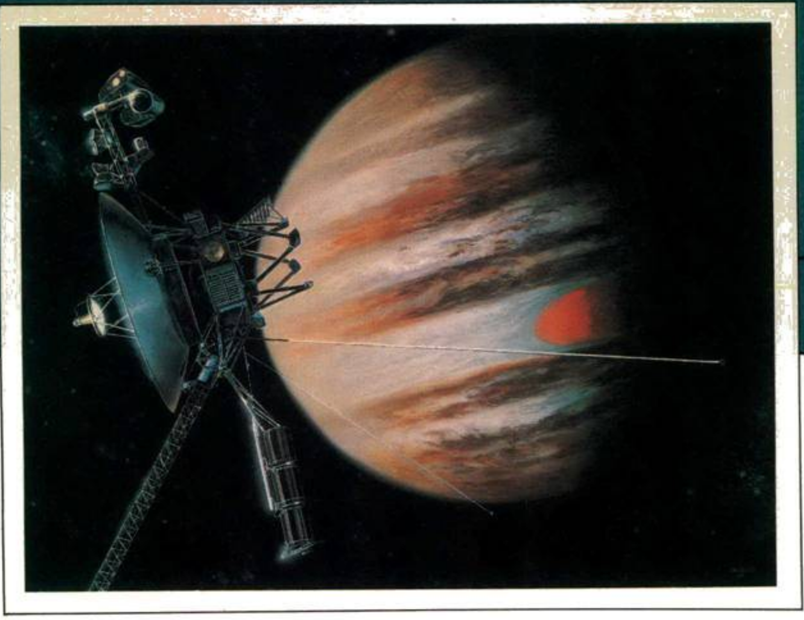

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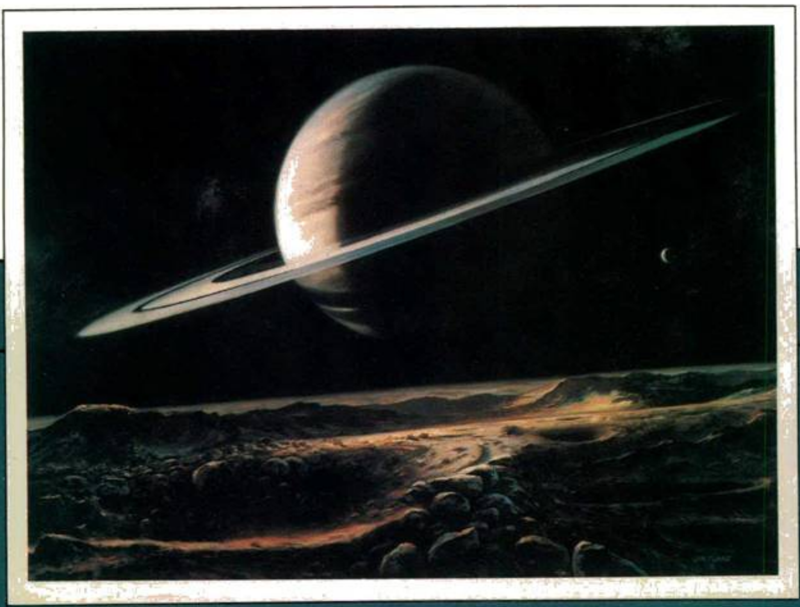

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Vol. 7, No. 7 *July 1979*

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COVER: The barred spiral galaxy NGC-6744 spins across this month's cover. Its spiral arms contain many recently formed brilliant blue stars, while the older stars near the nucleus shine with a pale yellow-green cast. Copyright © 1978 Department of Space Physics and Astronomy, Rice University. This page and facing: The southern hemisphere spiral NGC-5236 (also known as M-83) has remarkably regular lanes of dust backboning its arms. Notice a close correlation between ruddy hydrogen emission regions and resulting groups of young blue stars. Copyright © 1975-8 Anglo-Australian Telescope Board.

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What Makes a

Spiral Galaxy?

by

David Darling

We live within a galaxy whose dimensions dwarf the imagination. The numbers alone are spectacular: the Galaxy is 180,000 light-years across and contains over 100 billion stars. Observations reveal this vast structure to be built up from many interrelated parts — not only stars, but also wide lanes of dust, masses of unconsolidated gas, high-energy, sub-atomic particles, and magnetic fields.

Looking skywards to the constellation Andromeda, just west of the star Nu, you can spot a hazy patch of light — the two million light-year distant galaxy M-31. Half as massive again as the Milky Way Galaxy, this giant system boasts 300 billion suns.

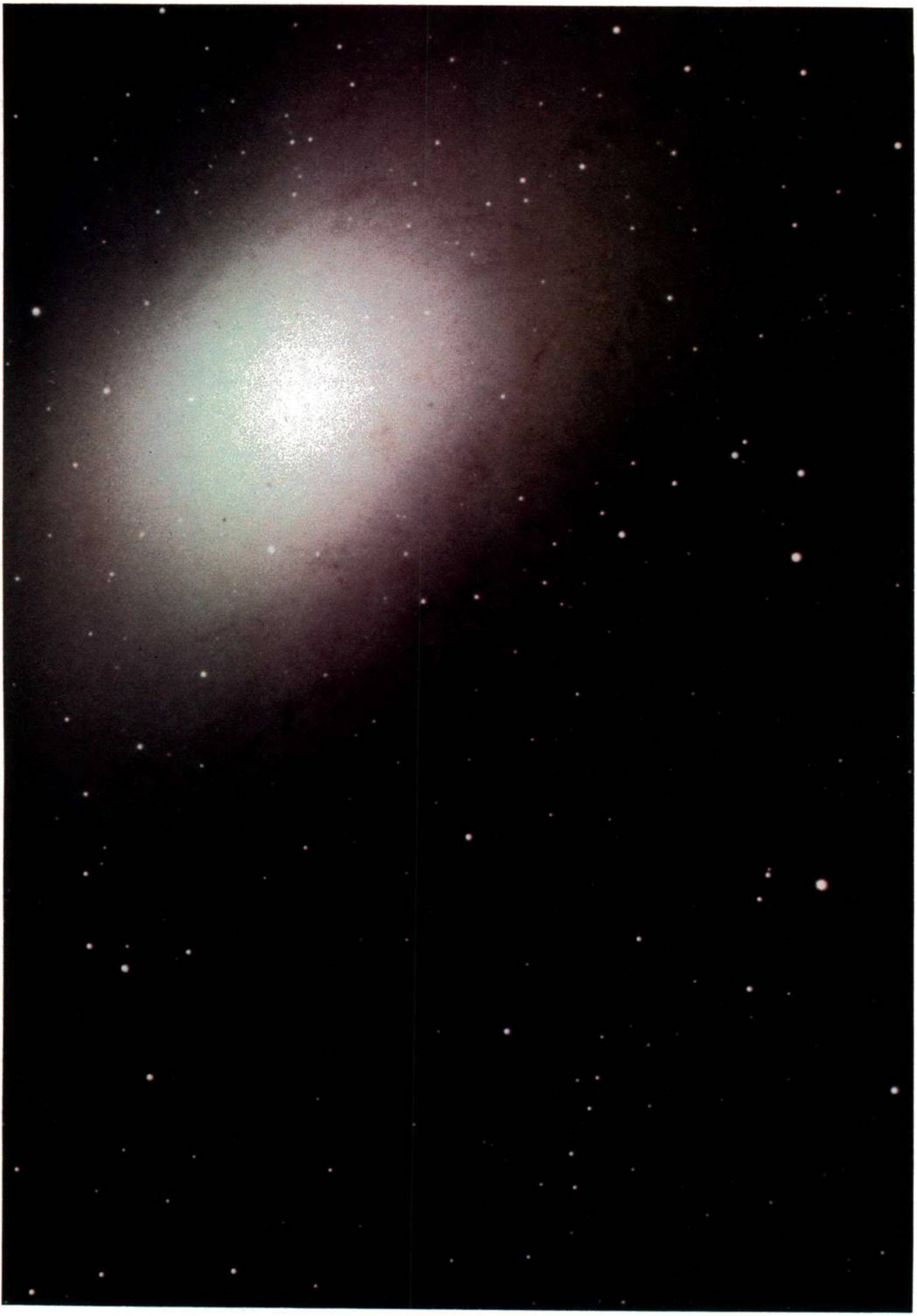
The modern myth of spiral galaxies like our own and Andromeda is that they're peaceful regions of space. Lacking in this popular conception are the breath-taking high-energy phenomena of the quasars and the drama of the weird so-called "active" galaxies. The reality, emerging from the last decade of research, is that galaxies are far more complex and dynamic than previously thought. And, although this is very difficult to be certain about, deep within the core of our Galaxy, events are occurring so violent as to suggest a direct structural or evolutionary link with quasar-like objects.

What do we mean by "spiral galaxy" anyway? What qualifications must a galaxy have before we can elect it to the illustrious "spiral" club?

Galactic Sub-systems

Stars, you say. Lots of them. All right, but what kind, and how should they be distributed? Take our own Galaxy as an example. We've every reason to suppose that it's a pretty typical spiral system, so we can easily generalize for other members of its genre too. Edge-on, the basic structure would be like two immense, thin frisbees with their hollow sides together, but with a prominent oval swelling in the middle. The frisbees represent the galactic disk, and the central swelling an elliptical region called the nuclear bulge. In addition, there's a faint,

Messier 31, a spiral that may resemble the Milky Way, is the nearest large galaxy. Its prominent nuclear bulge lies at the center of a thin flat disk of stars. The disk contains spiral arms, marked primarily by bright blue clumps of stars and dark streams of obscuring material. Photograph taken with a 6" f/5 Newtonian reflector on cooled Ektachrome 200 for a 30 minute exposure by Orien A. Ernest.



roughly spherical halo, centered on the nucleus, extending out to around 90,000 light-years.

That's an important starting point: the key concept of distinct sub-systems which comprise a spiral galaxy. For the present, think of the halo and nuclear bulge as being one sub-system, and the disk as being another. These two basic regions of a galaxy are made up from totally different components — the very stars within them are extremely dissimilar.

Let's leave that for a moment, though, and outline some other points which have a prominent part in our discussion. First, remember that there's a lot more to a spiral galaxy than just stars. Gas and dust are vital components too. Not only do they contribute extra mass to the overall system, but they're also the raw material from which new stars may form throughout the lifetime of the galaxy. In the "dustiest" galaxies, around one-quarter of the total mass is in the form of interstellar gas and dust. This figure drops to between 10% and 15% for the Milky Way system, and falls even further for some spirals where the nonstellar component inhabits only the innermost regions of the disk.

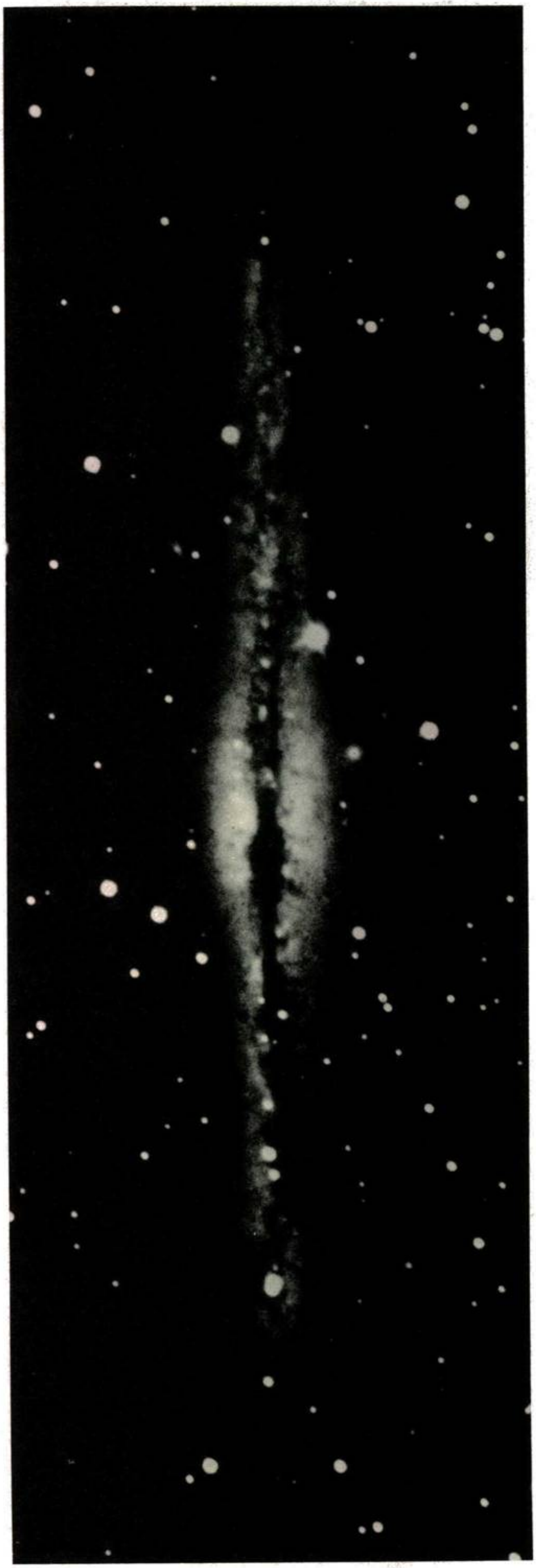
Other less obvious components play major roles. Intricate webs of the galactic magnetic field span all of interstellar space, and high-energy cosmic rays, electromagnetic and gravitational waves bathe every corner of the galaxy.

Finally, there's the galactic nucleus — engine room of the galaxy. From 30,000 light-years away we try to probe the mysteries of this extraordinary region but with difficulty: at optical wavelengths, we see nothing. Thick clouds of gas and dust soak up visible light as effectively as a solid wall. But at longer wavelengths, radiation gets through unhindered, and radio and infrared observations are our main source of data on the central parts of our Galaxy.

What do these observations tell us? That around one million solar masses of hot gas have been hurled from the galactic nucleus at high speeds in the fairly recent past. That close to the center exist a number of very peculiar small radio and infrared sources. That about five million solar masses lie within a few light-years of the center. We have no need to look to the quasars for puzzles — we have one giant enigma right on our doorstep.

The Forest and the Trees

Let's replace our high-resolution telephoto lens with a normal one and take in the whole galaxy



Left: The tremendous power of the 4-meter Kitt Peak optical telescope reveals wisps of dust silhouetted against the bright starry nuclear bulge of Messier 31. While the large bright stars in the picture are foreground stars (hence part of our Galaxy), the brightest individual stars in M-31's arms are faint groupings aligned with the dusty edges of the arms. Copyright © 1979 Association of Universities for Research in Astronomy, Inc. Right: Imagine viewing M-31 exactly edge-on. What you would see would resemble this photograph of NGC-891. The great disk is composed of billions of stars and dust lying close to a galactic plane; note also the nuclear bulge swelling out of the center of the disk. Hale Observatories photograph.

Left: Our own Milky Way contains material between its stars. Some of it is hydrogen gas that glows whenever it is near stars hot enough to excite it. This hydrogen gas may be material in clouds collapsing to form stars or heavy-element-contaminated hydrogen blown off by exploding stars. Great clouds of cool gas and particles of silicates and carbon (interstellar dust) absorb light; this material is visible when it blocks the light of stars and glowing gas lying behind it. This close-up near the star Gamma Cygni shows both glowing and absorbing material. Lick Observatory photograph. Right: The mixture of stars, emission regions, and dark nebulae along the plane of the Milky Way is so complex it almost defies description. Photograph by Rev. Ronald Royer.

again. Out here in the periphery we experience none of the violent events going on in the nucleus. Earth, one of a nine-planet family attending an unspectacular, yellow dwarf star, lies in a relatively tranquil region of space, journeying undisturbed on a 200 million year orbit of the distant galactic hub. From our viewpoint, what can we say about how stars and other materials are distributed throughout a spiral galaxy? In our own Galaxy, we're unable to see the structure because we're in it. But we're obviously not confined to a study of the Milky Way system alone; nearby spirals like Andromeda and M-33, members of the Local Group of galaxies, and the myriads of similar systems in other clusters of galaxies give us the opportunity to watch these objects from an external viewpoint.

Unlike the smooth, simple appearance of the ellipticals, spiral galaxies are rich in structure. Their very name derives from the presence of glorious spiral arms — complex bright and dark lanes winding away from a central nuclear bulge. Spirals are classified by the general appearance of these arms and their prominence in relation to the central region. Tightly wound spiral arms coupled with an extensive bright nucleus earn a galaxy the classification Sa. The progression Sb, Sc, and Sd, marks a transition to arms more and more loosely wrapped around a nucleus of diminishing size and brightness. M-31, the Great Galaxy in Andromeda, is a type Sb spiral — the same, in all probability, as our own.

That still leaves a class of spiral galaxy which we haven't yet considered: the so-called "barred spirals." The spiral arms of these objects originate from the ends of a very conspicuous luminous bar which spans the inner regions of the galaxy. If the Milky Way were a barred spiral, the bar could reach out as far as the neighborhood of the Sun, giving it a total extent of around 60,000 light-years. These fascinating variations on the spiral theme are far less well-understood than their normal counterparts.

Halo and Disk

Earlier, we talked about two major large-scale components of a spiral galaxy: the halo/nuclear bulge sub-system and the disk. Using the Milky Way, the galaxy in which we live, as an example, just what kind of objects do these regions contain?

Localized within the spiral arms of the disk, just a cosmic stone's throw from the galactic equatorial plane, are all the young objects of a spiral galaxy: the hot massive blue stars, no more than a few million years old, and the dense banks of gas and dust from which they've formed. This is the region of star births and of cataclysmic star deaths, a surprisingly narrow region too, stretching (on average) no further than 250 light-years from the galactic plane. In a system as large as ours, this young region is several hundred times wider than it is thick. Within this very thin band, the young open star clusters and straggling associations, dominated by the O-type suns and T Tauri variables, flash hurriedly through their brilliant careers.

Here, the massive supergiants, hugging the galactic plane, undergo colossal explosions during the late stages of their rapid evolution. The debris from these dramatic stellar blowouts comprises the familiar supernova remnants (the Crab Nebula in Taurus is the best known example) and their associated stellar nuclei, the pulsars. Fortunately, star material is recyclable. The matter thrown off by supernovae, novae, planetary nebulae, and stellar winds resupplies the interstellar medium. Finally, it may become part of some immense cloud from which new stars form.

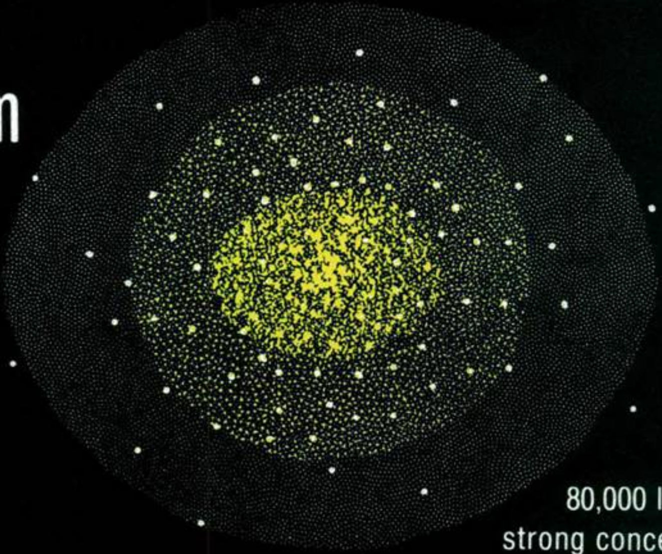
There's a whole range of interstellar clouds which crowd close to the galactic plane. As far as the hotbeds of star formation go, it's the warmer, denser molecular clouds which are the prime suspects. Regions like the 1500 light-year distant Orion Nebula, or the very much more massive Rosette Nebula, are the focus of action.

When details of the spiral structure concern us

Basic Galactic Components

Halo System

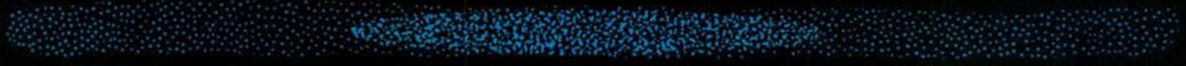
contents
40 billion stars
500 globular clusters



80,000 light years across
strong concentration toward center

+

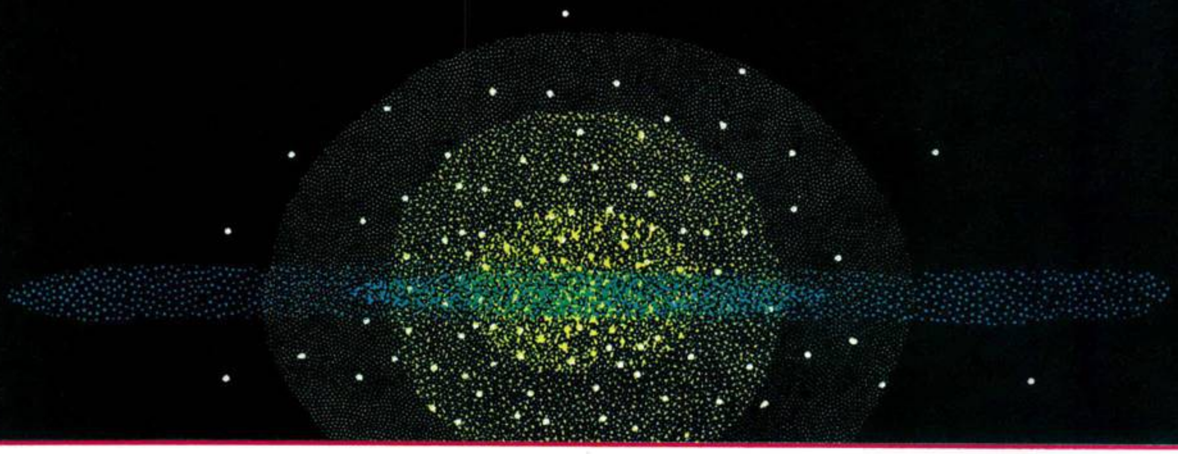
Disk System



contents
60 billion stars
interstellar gas
dust clouds
open clusters
stellar associations
HII regions

100,000 light years across
but only
several thousand light years thick

=



— the size and form of the spiral arms — we turn to the vast banks of neutral hydrogen emitting their telltale radio waves at 21 cm. Certain star types, too, are tracers of the spiral arms. Like an enormously intricate three-dimensional "connect-the-dot" puzzle, astronomers look to the spatial distribution of the bright young O and B stars, and the Cepheids, in their efforts to pinpoint the structure of the galaxy.

Out in the halo, that huge sphere nearly 200,000 light-years across which envelops the entire galaxy, things are a little different. There's hardly any of the gassy/dusty interstellar medium between the stars. No new stars are forming, and those that already exist are very old — as ancient as the galaxy itself. The loosely bound "galactic" clusters and stellar associations, so common in the disk, are absent from the halo. In their place we find a number of much larger groups of stars: the spectacular "globular" clusters.

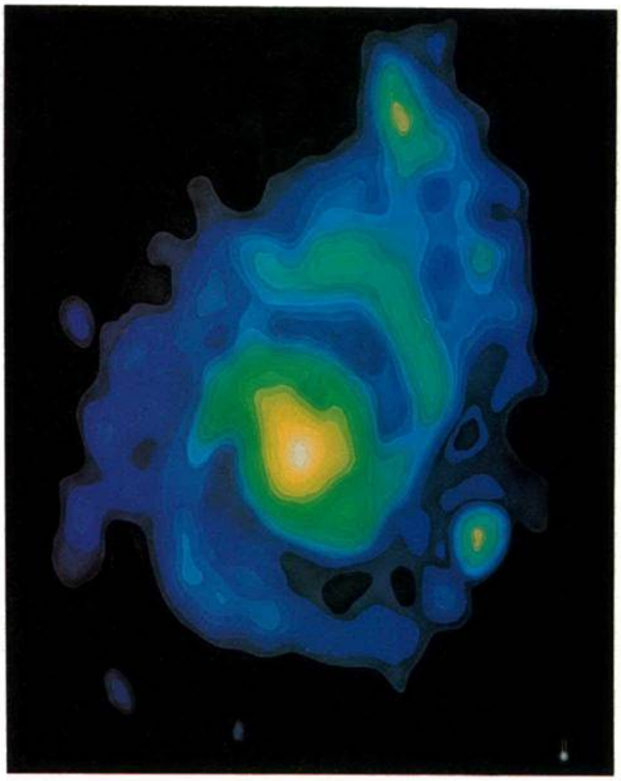
Often containing over a million suns, these giant balls of stars are very tightly bound by gravitation. "Evaporation" of stars from globulars is insignificant — in sharp contrast with the characteristic rapid breakup of the more open clusters of the disk.

There's no concentration of globular clusters in the galactic plane; rather, they are scattered throughout a sphere of some 60,000 light-years radius, with a moderate concentration towards the center of the galaxy. Outnumbered perhaps 40-to-1 by open clusters, only about 500 globulars populate the halo.

Halo Stars

Let's zoom in to look at the individual stars of a globular cluster. As soon as we start sampling them, we're struck immediately by two significant observations. First, the stars lack almost totally any elements heavier than helium; and second, their average stellar mass is very low. Taken together, these are pointers to extreme age. Why? The lower the mass of a star, the more slowly it burns its nuclear fuel. Stretching out the burning of the small reserve of hydrogen in their cores slowly over many billions of years, sub-solar-mass stars formed at the dawn of our Galaxy may still appear essentially unchanged to the present day. Only when a star has expended its core hydrogen do metals and other heavy elements start to accumulate in the stellar interior. This element-building process is a familiar feature of the massive supergiants in the dusty regions of the galactic plane, but generally fails to occur at all for halo objects.

It's a striking contrast: immense blue stars of the disk racing through their complex life-cycles before launching several solar masses of heavy element-contaminated star stuff on a journey through the galaxy, while the dim red stars of the halo, destined to outlive all other stars, change imperceptibly over the eons.



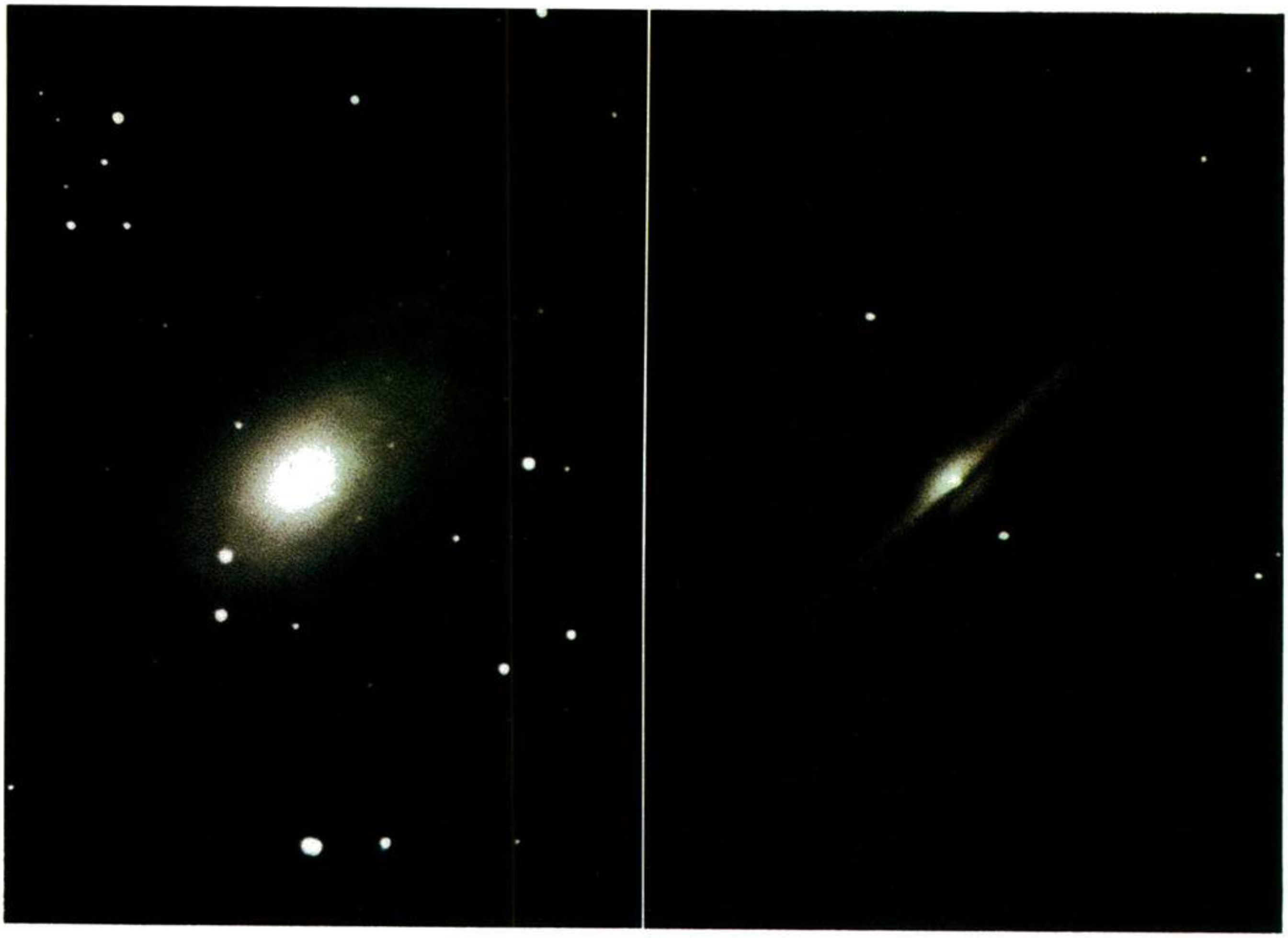
While a photograph made with visible light shows us where stars lie, radio mapping at 21 centimeters wavelength can show us the location of cool hydrogen atoms. This hydrogen line "radiograph" shows the spiral galaxy NGC-5194; a careful comparison with visible light images shows that hydrogen gas follows in a spiral pattern similar to that of the interarm dust. Artwork by Mark Paternostro based on Westerbork Observatory data.

Reddish, low-luminosity subdwarfs are the "bread and butter" stars of the halo. More prominent, though vastly outnumbered, are several other stellar types found chiefly within the globular clusters. RR Lyrae variables, for example, are conspicuous because of their high luminosity, even though the subdwarf minions outnumber them several thousand to one. The light variations of RR Lyrae stars are pretty well understood, and their so-called "period-luminosity" relationship gives astronomers an important way of estimating distances to objects in the halo.

Certain types of Cepheids and long-period variables are also found within globular clusters. Together with the more populous RR Lyrids, these stars are unusually massive and luminous for halo stars. In some cases, they have already started to "burn" helium at their cores.

"Populations" of Stars

Over thirty years ago, observational astronomer Walter Baade first applied the term "population" to subgalactic families of stars. He took all of the stars of the halo and nuclear bulge and labelled them population II. The remaining disk objects he called population I. Baade's work was a breakthrough in appreciating galactic structure, but his original scheme now seems like an oversimplification. Today, Baade's two major star



Spend some time looking at these two pictures; they show the nuclear bulge and disk structure of these two similar galaxies seen from different angles. The one on the left is NGC-3031, on the right, NGC-4565. The bulge is flattened not like an egg, but like a child's rubber ball that's been sat on. Though overexposed in both pictures, it is noticeably yellowish with population II stars. The disk is very thin, flat, slightly bluish with population I stars, and tapered toward the outside. The dust lanes, translucent spiral arm markers seen from above in NGC-3031, are quite opaque seen edge-on in NGC-4565. Note also that the dust lies in a much thinner band than the stellar component of the galactic disk. Not visible in either image is the very faint spherical galactic halo. Photographs by Bill Iburg with a Celestron 14 at f/5.5, 45 minute exposures on chilled Ektachrome 400.

groupings have become five, and there's a growing realization that a complete continuum of star types exists from the oldest population II object to the youngest (extreme) population I.

Extreme population I features the bright young open clusters of the planar region, the massive blue supergiants, the so-called "classical" Cepheids, and the T Tauri variables. It's an impressive assembly of very young objects — the showcase of any spiral galaxy — rich in the heavy elements formed during advanced evolutionary phases of earlier-generation stars.

Sweeping up through the new classification we meet the old population I types. These less massive, less luminous A stars, older than their extreme population I counterparts, move on orbits carrying them slightly further from the galactic plane.

And what of our own Sun? And Alpha Centauri? And all of the other stars whose age and composition place them somewhere in the limbo between old population I and young population II?

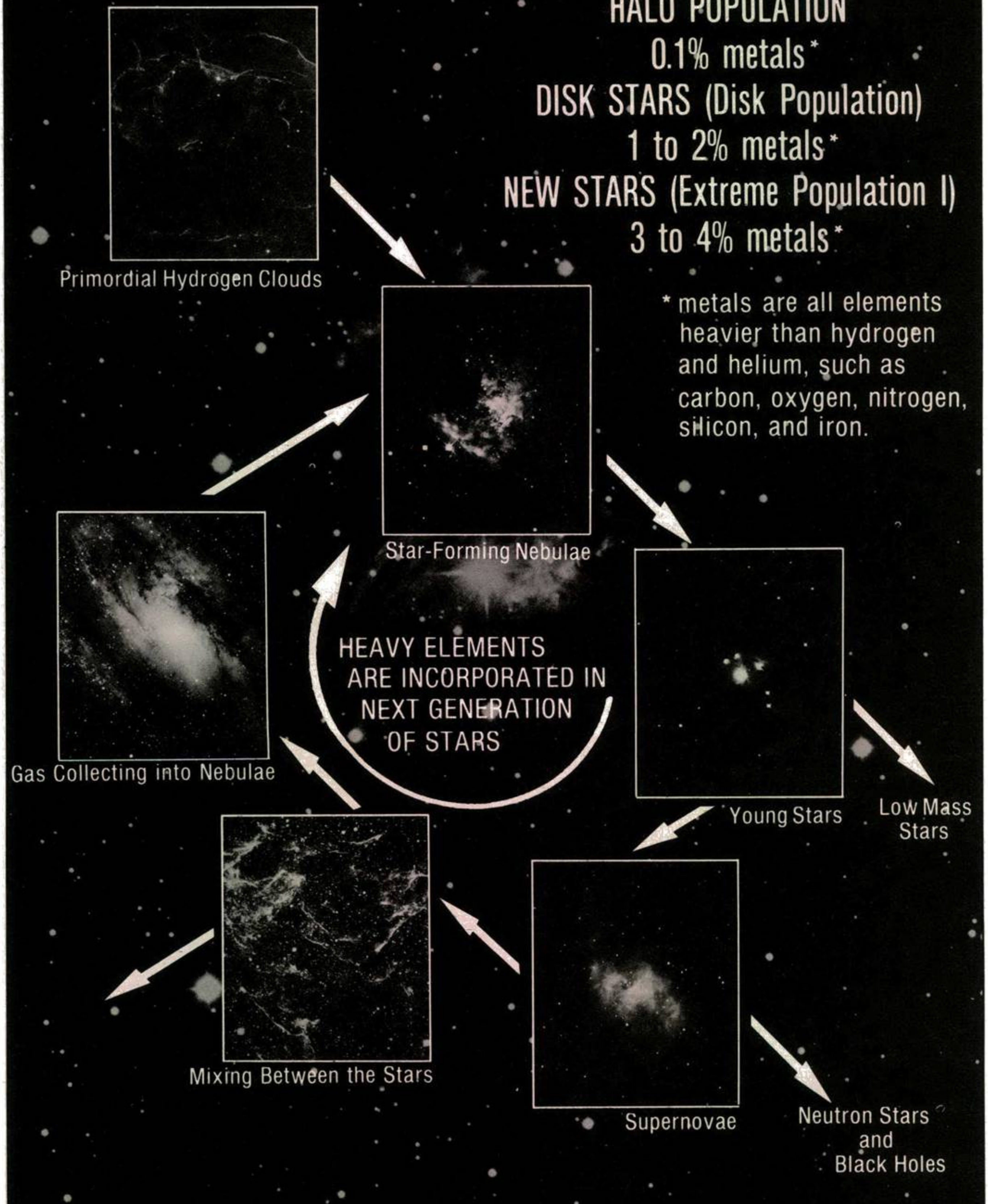
Middle-of-the-road stars like the Sun, together with their more evolutionarily advanced cousins the white dwarfs and the nuclei of planetary nebulae, make up a category called the disk population. Stars of the galactic nucleus are included too, and the general tendency of disk population members is to concentrate moderately toward the center of the galaxy. They're found scattered throughout a layer 1500 light-years thick on either side of the galactic plane.

Population II has two categories now, like population I. Young population II is composed of many stars from the nuclear bulge, certain long-period variables, and stars moving with high speed either towards or away from the plane. It's a fact of life in spiral galaxies that the faster something moves in a direction at right angles to the galactic plane, the less confined it tends to be to the planar region. Orbital shape, too, is a key mark of distinction between the various population types. Extreme population I objects move through the plane in almost circular orbits, whereas the globular clusters, subdwarfs, and longer period RR Lyraes of the halo population II hurtle along decidedly non-circular paths.

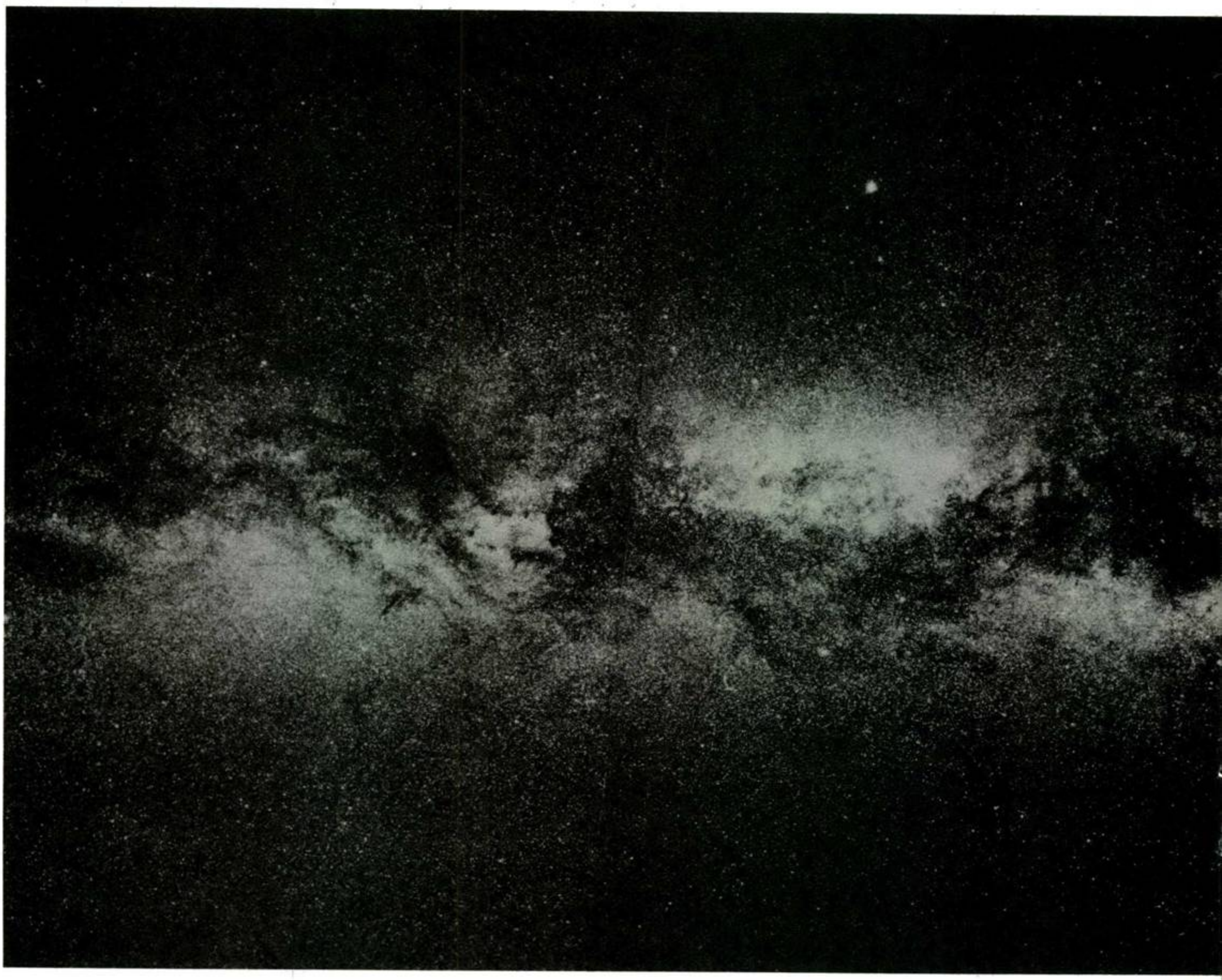
RECYCLING STELLAR MATERIAL

HALO POPULATION
0.1% metals*
DISK STARS (Disk Population)
1 to 2% metals*
NEW STARS (Extreme Population I)
3 to 4% metals*

* metals are all elements heavier than hydrogen and helium, such as carbon, oxygen, nitrogen, silicon, and iron.


Primordial Hydrogen Clouds
Star-Forming Nebulae
Young Stars
Low Mass Stars
Supernovae
Neutron Stars and Black Holes
Mixing Between the Stars
Gas Collecting into Nebulae
HEAVY ELEMENTS ARE INCORPORATED IN NEXT GENERATION OF STARS

Photographs courtesy Hale, Lick, Steward, and Kitt Peak Observatories



A composite of wide-angle photographs of the Milky Way reveals a striking similarity in appearance to NGC-891 and NGC-4565, edge-on galaxies portrayed on pages 9 and 14. Stars thin out away from the plane of the galaxy (which runs through the center of the picture), and reach maximum concentration in the area most obscured by dust and gas clouds clinging to the galactic plane. Note that outer parts of the nuclear bulge are clearly visible in Sagittarius, while the nucleus is completely obscured. Hale Observatories photograph.

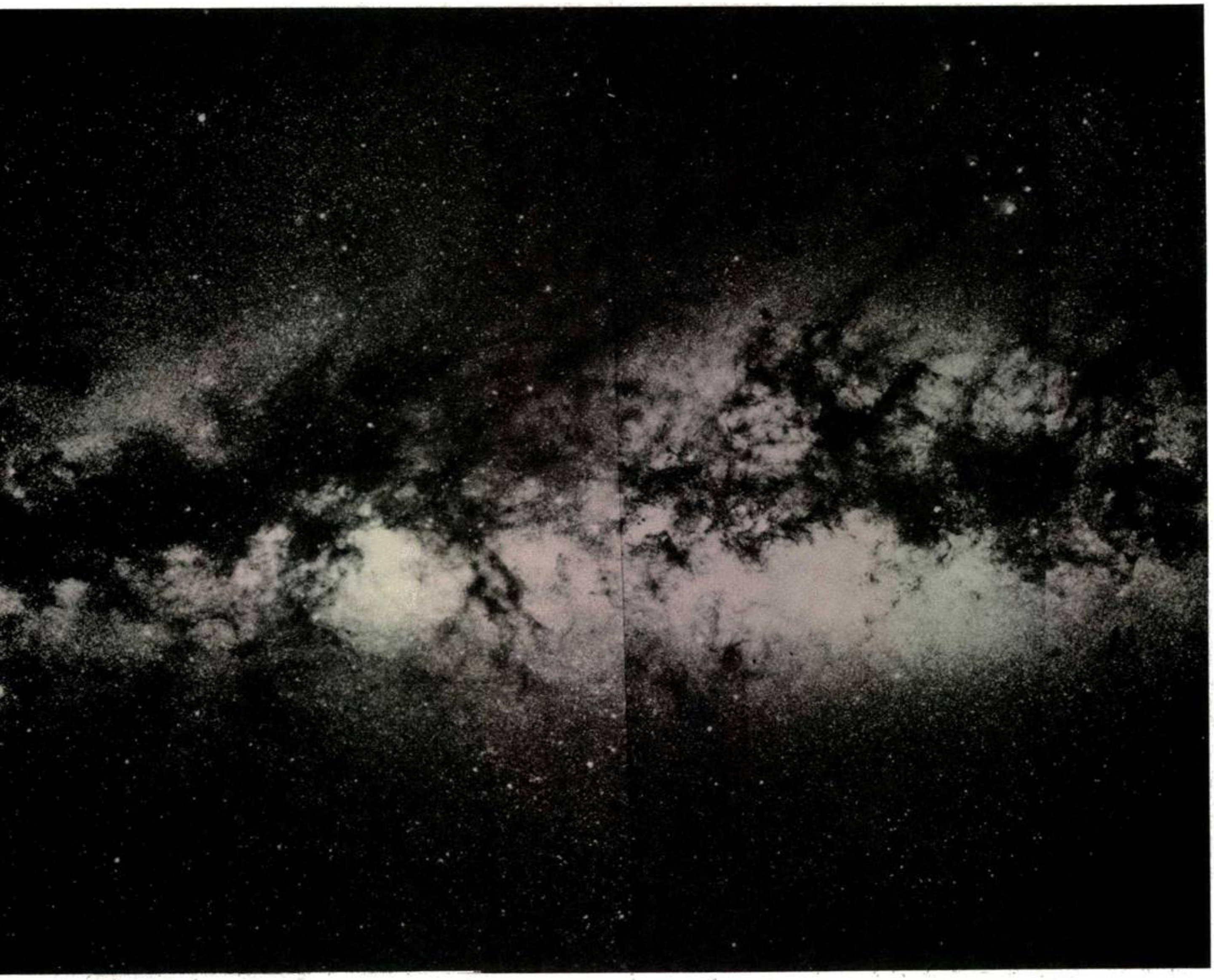
Back to the Beginning

And now for a little digression. Our starting point was the question: "what makes a spiral galaxy?" Consider, for a moment, the related question: "what *made* a spiral galaxy?" Given the present layout of stars and other matter in the Galaxy, what can we deduce about its origins?

Time: a few hundred million years A.B.B. (After the Big Bang). A hundred billion solar mass cloud of hydrogen/helium, roughly spherical, cool, and rotating slowly, contracted under its own gravitational pull. Local regions of higher density coalesced first, and within them the first generation of stars formed. These were the globular clusters, first inhabitants of a galaxy still in the process of contraction. The objects of the halo we see are a fossil remnant of the original spherical proto-galaxy.

Next came the nuclear bulge. As the innermost regions of the proto-galaxy set the pace in gravitational collapse, the first members of the nuclear region turned on their hydrogen reactors. The process gathered momentum, the smooth elliptical bulge resulting from stars lurching through a fast-changing gravitational field. The cosmic roller coaster ride which greeted any new star formed in the galaxy at this time created stellar orbits which were like "averages" of all the other orbital paths in the rotating cloud. The bulge was thus formed smooth, uniform, egg-shaped.

Elliptical galaxies come to the end of their formation period right at this point. Spirals aren't so meticulous in cleaning up their hydrogen-helium mix; they're left with a significant amount of unused gas, which flattens out into a wide disk around the central bulge. Here the first generations of population I stars were born from a "clean" hydrogen/helium mix, to be followed over the eons



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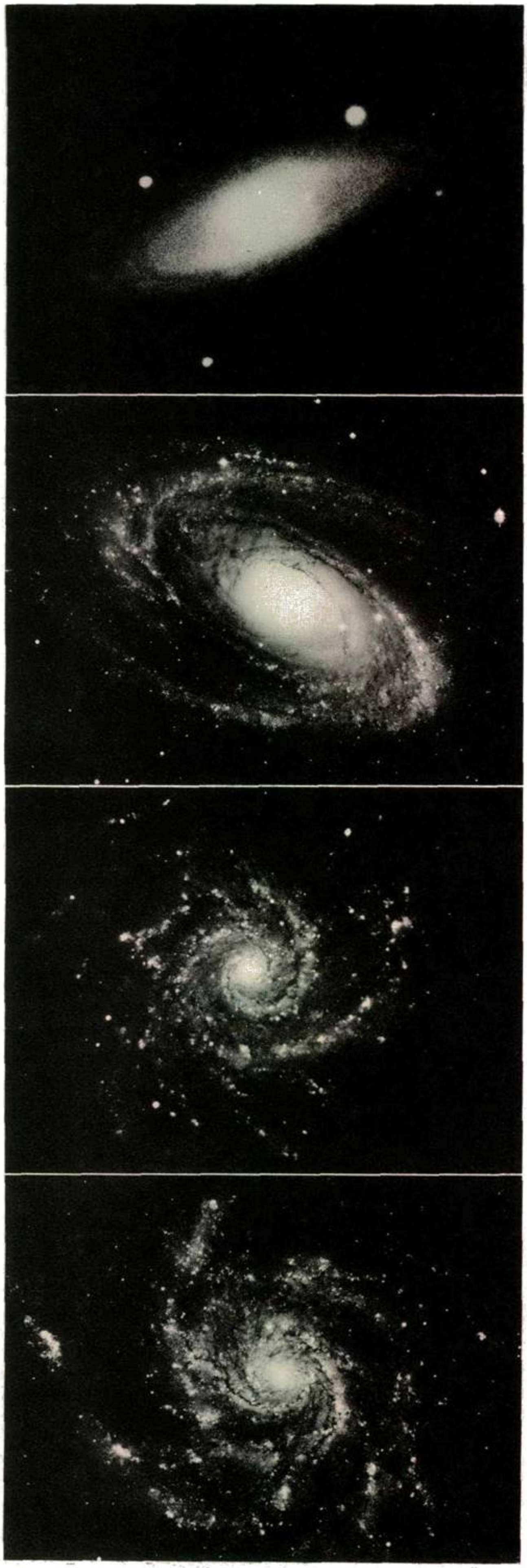


The sequence from Sa (top) through Sd (bottom) galaxies is shown here illustrated by NGC-2811, 3031, 628, and 5457. The size and importance of the arms grow through the sequence while the size and importance of the nucleus decrease. Hale Observatories photographs.

by successive generations of stars made from an increasingly "dirty" mix filled with heavy elements from exploded first generation stars.

As we study the Galaxy today, we still see the frozen remains of the evolving proto-galaxy preserved from that early epoch of the universe. The globular clusters of the halo population II relentlessly follow their ancient paths, echoes from the time when the Galaxy had a different shape.

Spirality

Let's now return to ask "what makes a spiral galaxy?" We still must clear up a pretty major issue though: what's responsible for the spiral nature of these systems? Exactly what is a spiral arm and what does it contain?

Oddly enough, a spiral arm isn't what it appears to be. It doesn't represent a permanent local concentration of disk material. If it did, we'd be faced with an impossible paradox: spiral arms are known to survive many complete galactic rotations, yet any permanent material arm would get hopelessly wrapped around the nuclear bulge after just a handful of turns. What's the answer? Modern astrophysics comes to the rescue with the density wave theory. It proposes that spiral structure comes about through the outward motion of density waves; a spiral arm turns out to be nothing more than the crest of a moving density wave.

Although many of the implications of spiral density wave theory are still to be uncovered, it seems that the existence of dust lanes in spiral galaxies is one of the more significant predictions. It's a strong boost for an already well-established theory. The idea is that shock waves are set up in the interstellar gas by the gravity field of the density wave. Carrying the dust particles with it, the gas gets compressed by the passage of the shock. Bingo! You have a dust lane.

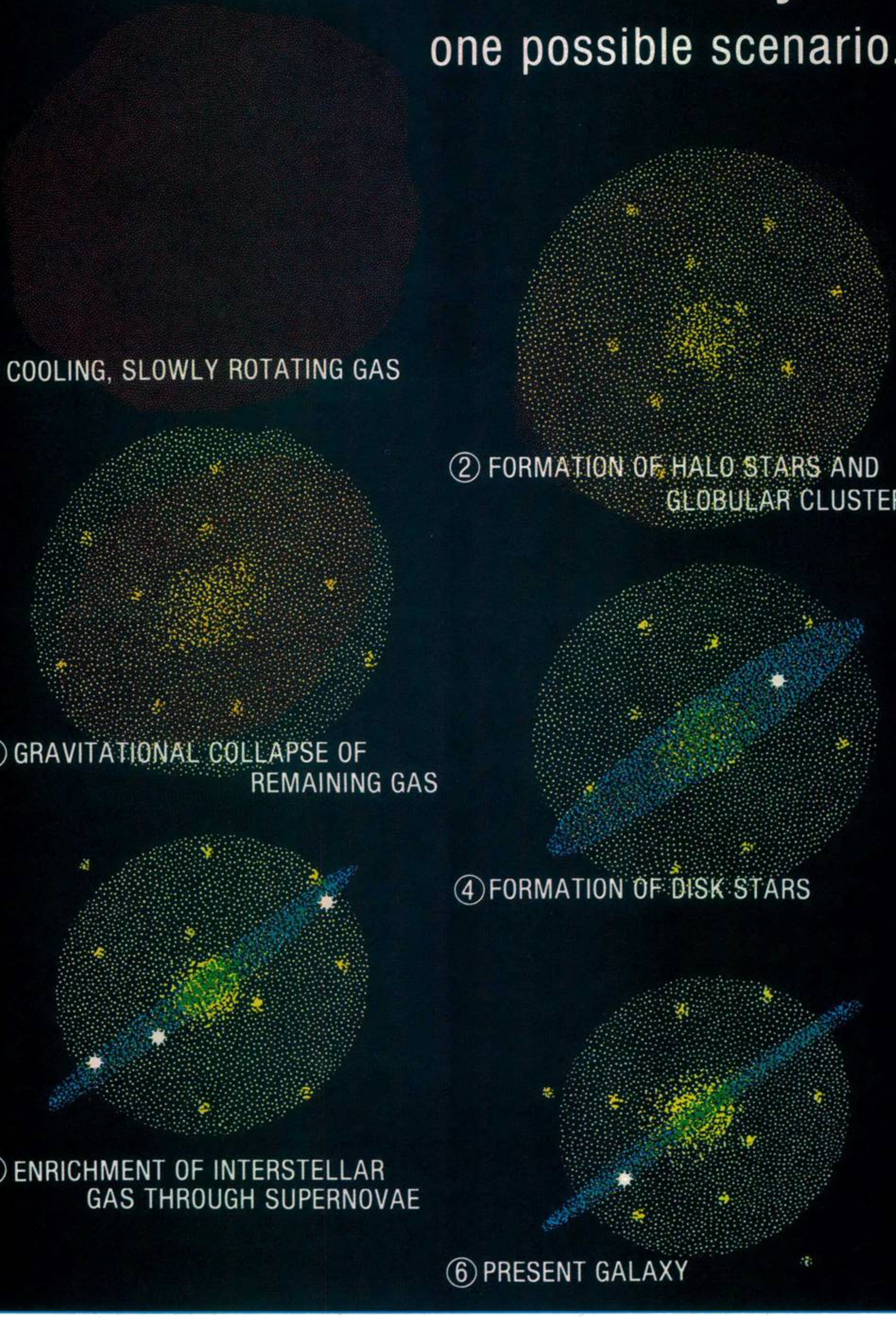
Star formation at the leading edge of spiral density waves has also been suggested. On the face of it, the idea is entirely reasonable. The compressed gas and dust behind the shock wave might be an excellent region for the collapse of material to the molecular cloud, and, eventually, the proto-star stage. But we don't really know yet; so far it's just an educated guess, without the strong theoretical support which only many hours of work with the most powerful computers available will bring.

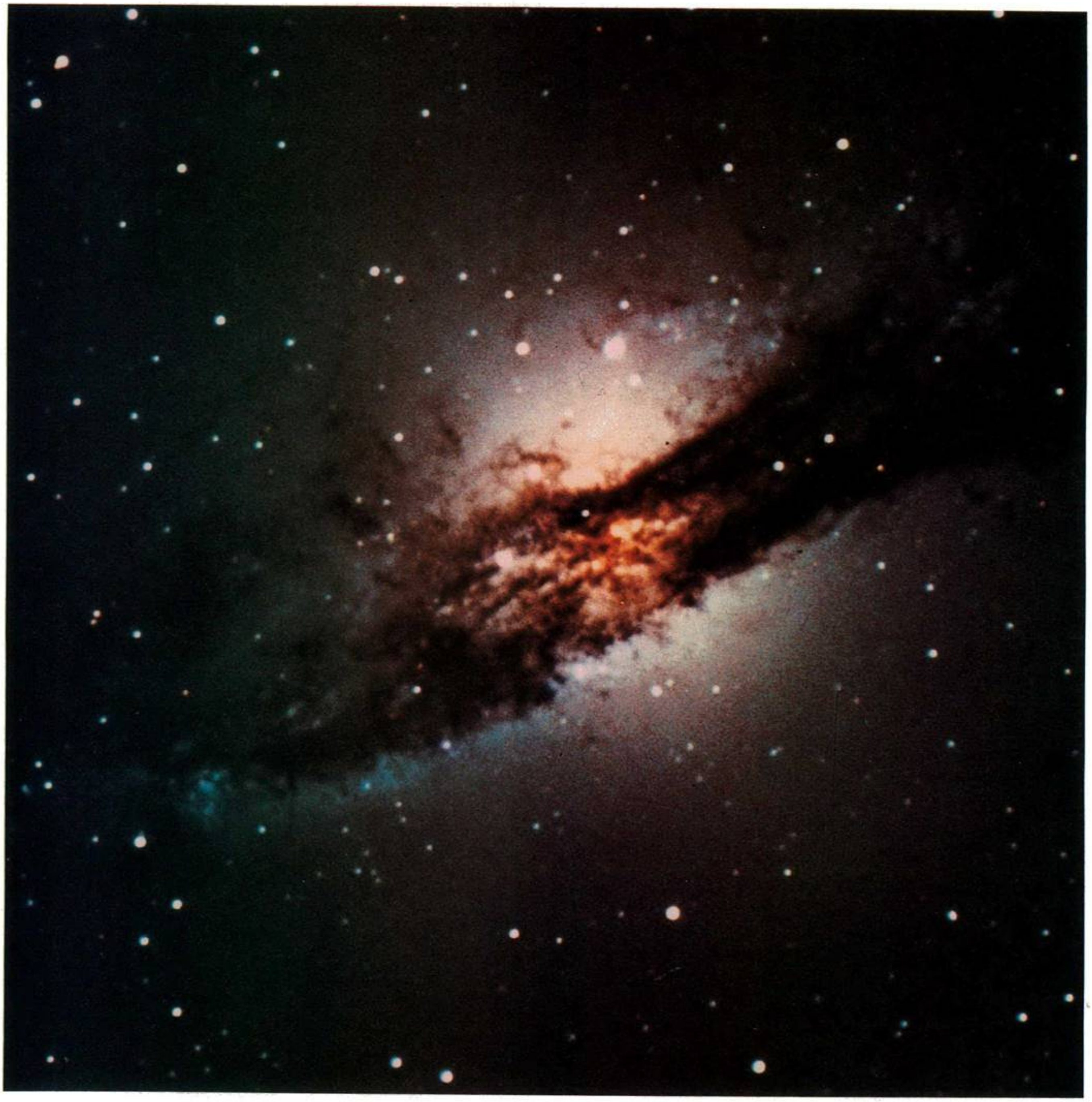
Have we finally answered the question "what makes a spiral galaxy?" Perhaps. But what of those strange events that we've recently glimpsed in the galactic nucleus. Why, for instance, is a giant million-solar-mass torus of gas billowing outwards from the center of our Galaxy?

Fast-moving gas clouds, intense X-ray,

the Formation of a Galaxy

one possible scenario...


① COOLING, SLOWLY ROTATING GAS
② FORMATION OF HALO STARS AND GLOBULAR CLUSTERS
③ GRAVITATIONAL COLLAPSE OF REMAINING GAS
④ FORMATION OF DISK STARS
⑤ ENRICHMENT OF INTERSTELLAR GAS THROUGH SUPERNOVAE
⑥ PRESENT GALAXY

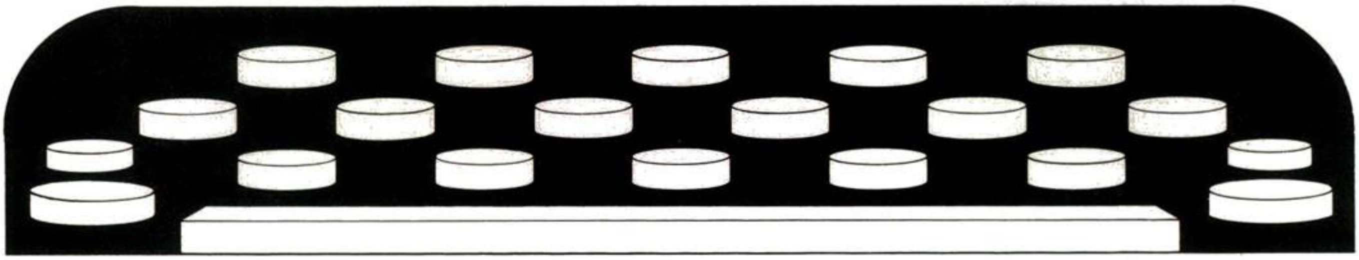


NGC-5128 is one of the more fascinating objects in the sky. An elliptical galaxy, a radio source (Centaurus A), and an X-ray emitter, it is possibly the site of some kind of explosion on a galactic scale. Optically its greatest peculiarity is a massive ring of material around the "equator" — a feature more appropriate to a spiral galaxy. Near the ring of material are several arcuate regions of star formation — another spiral characteristic. The newly-formed stars are blue compared to the yellow-white stars that make up the parent galaxy. Copyright © 1979 Association of Universities for Research in Astronomy, Inc.

infrared and radio wave sources, and strong concentrations of matter are all known to exist in the maelstrom of the galactic nucleus. Whether such phenomena are features of other apparently normal spirals we cannot yet say. Exotic energy sources, including a massive black hole which swallows stars, have been suggested as the driving force behind the explosions at the heart of our Galaxy. Black holes, too, may lurk at the cores of the ancient globular clusters, perhaps explaining the curious and unsuspected X-ray emission from these objects.

The next decade will see spaceborne instruments working in many parts of the spectrum to draw aside some of the tantalizing veils from these mysteries. Spiral galaxies are not always what they seem to be. Their intricate lanes of gas and dust, and their complex patterns of dazzling stars, hide an inner system of mysteries which we're only just beginning to appreciate.

David Darling received his doctorate from the University of Manchester (England). For his thesis topic, he studied the dynamics of multi-envelope planetary nebulae, and has written about these objects in ASTRONOMY.



Sir / Mr. Parker's simple formulation of the Green Bank equation to determine the probable number of "advanced civilizations that we could communicate with" ignores several critical factors discussed by Bracewell (1), Kreifeldt (2), Wertz (3), and others. Briefly, since our range of signal detection is less than 1000 light-years (4), humanity is primarily concerned with the density of civilizations in our "neighborhood." This alters the proportion of stars of the proper age and metallic content. The growth of communication networks is affected by local inhomogenieties of stellar distribution. The existence of a small fraction of long-lived civilizations greatly increases the total number of civilizations. Also, even a small level of colonization greatly increases the longevity and density of civilizations.

The arbitrary estimate that one of ten suitable stars has planets seems conservative. Brown (5) has shown, from astronomical evidence, that all stars may have planets. The computer simulations of planetary formation of Dole (6) and Sagan (7) have produced solar systems which resemble ours in quantity, size, orientation, and spacing of planets. Furthermore, Dole (8) investigated critical factors such as planetary rotation rate, axial tilt, and atmospheric generation in deriving his estimate of 600 million habitable planets. Dole (9) and MacDonald (10) have shown that there is a linear relationship between planetary mass and rotation rate such that a planet with a mass suitable for possession of a breathable atmosphere will very likely have a rotation rate similar to Earth's. Dole has also explained the dynamical cause of this relationship. The Earth's rotation rate has varied by at least 40%, because of the gravitational influence of the Moon (11), without preventing the development of life. The problem with Venus and Mars is that they are near the edges of our ecosphere and are not the right size for their location. If Mars were larger or Venus were smaller, either could probably have a suitable atmosphere.

The inference that the probability of the existence of a species possessing manipulative intelligence is one in 10 billion for each habitable planet with life, could only be true if the emergence and survival of species were totally random. Natural selection favors only variations which are successful adaptations to a terrestrial environment. The phenomena of evolutionary convergence and parallelism (12) demonstrate that the structures of many human organs are similar to those of other diverse genera and are favored by evolution. These factors have been discussed repeatedly in the literature of exobiology.

Although colonization of the nearest stars may be possible, I can see no motivation for abundant interstellar exploration that would offset the incredible economic expense, especially when the convenient alternative of interstellar communication is available.

Gordon W. Pace
Portland, OR

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Mr. Pace / My estimate that one of the ten suitable stars has planets is no doubt quite conservative. Most people select a number closer to one. But to quote Carl Sagan, "The actual number is likely about 0.5 ...." The truth is, we have very little to go on in arriving at this and some of the other numbers in our probability scheme, but I will go along with you. Please note that I was very optimisitic on the next point in the article, so maybe that makes up for it.

There are several points in your letter with which I do not agree. In making his estimate of 600 million, for example, I don't believe that Dole has a factor that accounts for atmospheric generation (admittedly, he does a bit of hand-waving). Also, in regard to the angle of inclination, Dole shows that there is some effect on the ecosphere. In fact, he states that an inclination of 54° is probably an upper limit.

And, indeed, Dole and MacDonald do show that there is an approximate linear relation between planetary mass and rotation rate for the planets of our solar system assuming there are no tidal forces involved (Mercury, Venus, our Moon, and to some extent even the Earth, do not satisfy this relationship). But do we know for certain that this applies to all solar systems?

With regard to the point made by James Christian concerning the fact that only one species of the 10 billion on Earth is highly intelligent, I do not seriously suggest that we divide our estimate by 10 billion. I'm only throwing this information out for consideration. This — and many other factors — are not always taken into consideration.

Finally, Michael Hart of Systems and Applied Sciences of Maryland (see **Astro News** *in this issue) has recently completed some related computer simulations. He examines the habitable regions of stars slightly larger and slightly smaller than our Sun and concludes that there are serious problems with ultraviolet radiation in stars of 1.1 solar masses — just slightly more massive than the Sun. He also shows that* *serious problems exist for stars only slightly smaller than our Sun. Hart concludes that there are likely fewer planets in our galaxy suitable for life than previously thought.*

Barry Parker, Professor
Dept. of Physics and Astronomy
Idaho State University
Pocatello, ID

Sir / On page 45 in the March 1979 issue of ASTRONOMY (in the article "Patrolling the Planets"), I was surprised to find the statement that for the Viking missions, "the picture part of the mission is over."

The fact is that cameras on the landers on the martian surface are still operating, and those on Orbiter 1 were operating as of March 5th. They have just been shut down temporarily to make way for the intense activity at JPL and its tracking stations required by the Jupiter encounters of the two Voyager spacecraft. Our current plans are to record a picture on Lander 1 approximately every week for the next ten years. Whenever a ground station is available at the time when the lander is programmed to read out the picture on the telemetry link, the picture will be received on Earth. Meteorology data will also be returned. We also hope to reactivate the orbiter in late summer for a few weeks or months after the second Voyager encounter to take some more close looks at sites where we might wish to land sometime in the '80s or '90s.

Conway W. Snyder
Viking Project Scientist
Jet Propulsion Laboratory

Sir / I read with interest the article "Pluto: Planet or Impostor?" by Ian Ridpath in the December issue of ASTRONOMY. I note that at the bottom of page 9 Mr. Ridpath states: "Tombaugh continued his photographic search around the ecliptic, but no other planets were found...."

This is certainly the understatement of the year. Considering the possibility of planets with greater orbital inclination, I searched strips around the sky parallel to the zodiac until I had covered 70% of the sky. I searched with great care and thoroughness; time spent at the blink microscope totaled 7,000 hours and I saw individually 90 million star images!

The discovery of Pluto's satellite Charon, by Christy at the U.S. Naval Observatory at Flagstaff, was a most important contribution. It gave the first reliable value for the mass and density of Pluto — a very interesting discovery because it suggests a composition similar to the four giant planets and to comets.

It now appears that Pluto's diameter is still more than half the diameter of the planet Mercury, and much larger than the largest asteroid, Ceres. Pluto's orbital eccentricity and inclination are not greatly different from the planet Mercury; therefore, I fail to see why Pluto should be demoted from a planet's status as yet. Let's not knock it; the effort, care, and cost to find Pluto were tremendous, as I well know. Many writers assume that when Pluto was found, the search ended. Quite to the contrary — I did that search. Believe me, such bodies are scarce!

I certainly enjoy your ASTRONOMY magazine. With best regards,

Clyde W. Tombaugh
Las Cruces, NM

Dr. Tombaugh / In asking whether Pluto is a planet or not, Mr. Ridpath created an interesting and highly intriguing article perhaps somewhat more successfully than he cast doubt on Pluto's planethood. Nevertheless, recent discoveries have made the outer parts of the solar system seem more and more interesting — and definitely a place we want to know more about.

Readers interested in Tombaugh's search should read chapter 2 in volume 3 of **Planets and Satellites**, *University of Chicago Press (1961), edited by G.P. Kuiper and B.M. Middlehurst. Copies will be available in most university libraries and larger public libraries.*

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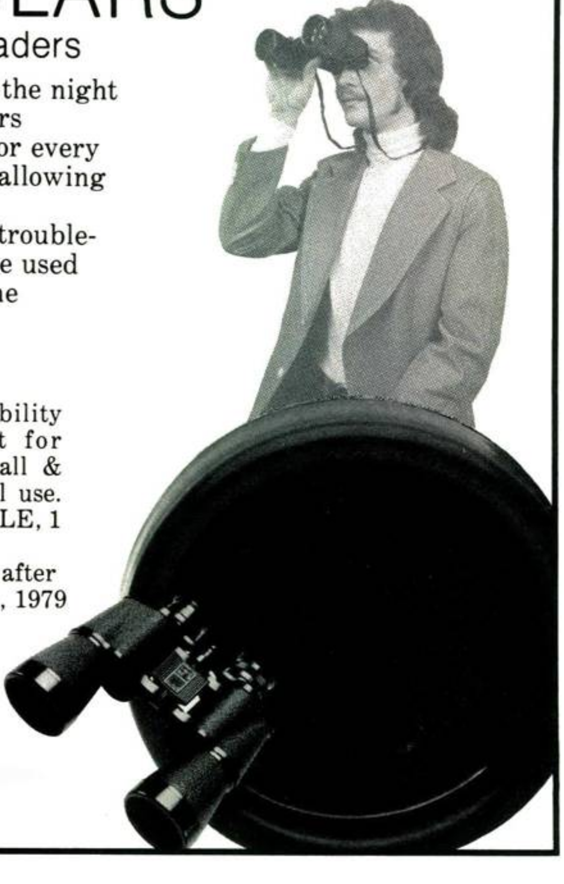


Behind the Scenes

ASTRONOMY

Grows and Changes

For its first three years, ASTRONOMY was a 48 page magazine. It grew to 64 pages and stayed that size for a year. Then, for over four years, ASTRONOMY remained an 80 page magazine. Your June 1979 issue however was 84 pages, and this July issue holds 88. ASTRONOMY is growing again.

You might ask why ASTRONOMY didn't become larger sooner — especially if you're a charter subscriber and remember some of Stephen Walther's more optimistic memos. He expected ASTRONOMY to become much bigger much sooner. In fact, we surely *would* have grown if today's paper, printing, and postage cost what they did in 1975. But they don't: the cost of paper is double what it was then, so our printing bill has grown by leaps and bounds, and the cost of mailing has inflated at a remarkable rate — 55% last year alone. Another second class postage increase of 22% is scheduled for July 6 this year. Our circulation growth has largely offset those increases, but never enough to permit publishing a larger magazine. Until now.

ASTRONOMY's larger readership (over 95,000 with this issue) is attracting advertisers as never before. In fact, under the guidance of Robert Schmall, our Advertising Director, we find ourselves almost too popular. You see, some time ago we decreed that advertising would never take more than about 30% of our pages; but we felt that ASTRONOMY's format could absorb that many ads and still remain the World's Most Beautiful Astronomy Magazine. Advertising has now reached that level, and in some issues even exceeded it, within the last year. By bringing advertiser's messages to you, we feel we're providing a useful service — up to a point. After that point, however, we'd just be taking feature and article pages out of your magazine.

Over the last four years, and in particular in the last year, the editorial staff has put a lot of thought into getting the most out of the available page space. We've worked hard to redesign some parts of ASTRONOMY to bring you all the magazine content you deserve. For example, about a year ago we switched to the more efficient three-column format in Gazer's Gazette, Equipment Atlas, and Photography in Astronomy. We made the Planet Finder an information-packed single page (instead of two pages) in order to free more space in Sky Almanac for photographs from our readers. Now, although Star Dome now occupies six pages instead of seven, nothing is missing; it's only more compact.

AstroNews, too, recently changed to a new format, not only because we can bring you about one-third more news in the same space, but we wanted a better "look." Our cover, while retaining much of the classic ASTRONOMY design, is now bolder, more vigorous, and more successful on a growing number of newsstands.

But the advertising demand is still there, and growing. The solution? Adding pages, obviously, not only for the advertiser but for you, our reader. We will maintain the current editorial-to-advertising ratio (two pages editorial material for each page of advertising) by bringing you more pages of features, observing information, news, pictures, and solid understandable writing.

And this month we're adding an entirely new department to this magazine: **ASTRONOMY Forum. Forum** will bring you a wide variety of fascinating reading with first rate articles on the many thought-provoking dimensions of astronomy. As this department grows, you'll find interviews, opinion, solid science writing, and "the news behind the news." **Forum** may sometimes tax your understanding, and it'll occasionally try your patience. You'll travel behind the scenes into observatories, explore the labyrinths of modern cosmological thinking, and learn what makes modern astronomy "tick." We think you'll like it.

Of course we'd like to know what you'd like to see in **Forum**, too. Just drop me a note or a postcard, and I'll try to put your ideas into action.

This year, by the way, we're offering our 1978 index free to any reader who sends us a self-addressed stamped business (long) envelope. Our word processing and photo-typesetting machines have made preparing the index so much easier and less expensive that we thought we'd pass the savings on to you. Please mark "1978 Index" on the outside of your letter to help our mailroom staff get your index back to you quickly and efficiently. Indexes for 1973-4 (combined), 1975, 1976, and 1977 are available for $1 each.

One final note: this month marks the tenth anniversary of the first landing on the Moon. I took the picture on this page from the face of a friend's TV set as I watched, totally awe-struck, "men from the planet Earth" walking about on the surface of another planet. That feeling comes back sometimes when I look at the Viking Mars pictures or the Voyager Jupiter pictures and wonder when they too will receive their first visitor from planet Earth.

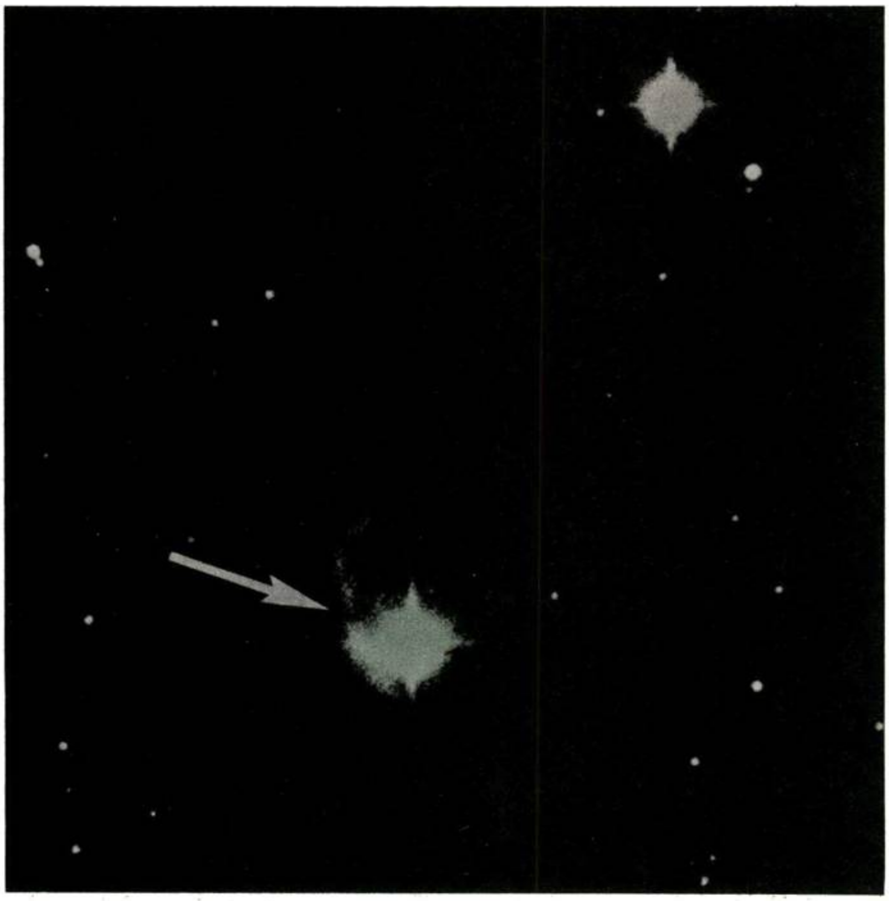
Richard Berry

Richard Berry

ASTRONOMY forum

The Amazing Fuors

If you haven't heard of a fuor, don't be alarmed. They aren't potential invaders of our galaxy, but they *are* a most interesting and highly select club of stars. The term, a rather uncomfortably glib one, was coined by the famous Russian astrophysicist Viktor Ambartsumian. It refers to stars which have followed the example of the variable star FU Orionis. In 1936 this previously faint star in northern Orion flared to about tenth magnitude, an increase in brightness of about two hundred times, in a mere four months. Now you might feel there is nothing remarkable in that, and you're right. Many novae, for example, have achieved such a flare. However, unlike novae which fade after maximum light, FU Orionis has remained at essentially constant brightness since the outburst, and that *is* remarkable. Nothing is known of the nature of FU Orionis before the flare; no one had attempted to obtain a spectrum of this obscure faint object.



V1057 Cygni

George Herbig, Lick Observatory

At the head of Orion lies the bright hot star Lambda Orionis which has produced a large glowing nebula in its vicinity. To the east side of this nebula is a dark cloud of dense dusty material in which FU Orionis appears to lie. In fact, we can definitely link FU Orionis with this dusty zone.

Imagine that you are a piece of dusty gas cloud sitting some considerable distance from the pre-outburst star. You function as a feeble mirror to reflect a microscopic fraction of the starlight in the direction of Earth, but so faint is this reflection that it is not visible to terrestrials. Following the flare, the star brightens so much that its light can be recognized in reflection from the cloud, even at the Earth's distance. However, the cloud doesn't light up immediately in response to the star. Light takes a certain period of time to travel the distance from the star to the cloudy mirror, and then on to Earth. The amount of the delay between the brightening of the star and the lighting up of the cloud is directly related to the distance from the star to the cloud. After the flare, a small reflection nebulosity indeed appeared around FU Orionis, establishing the star's relative proximity to the dark clouds.

The association of FU Orionis with dark matter suggests that the flare is more likely related to an early phase in the life of a young star than to the end of its stellar evolution. This follows because young stars are born in nurseries rich with glowing clouds of gas and opaque dust.

After maximum light, the star showed a spectrum characteristic of a temperature somewhat hotter than that of our Sun, and gave some evidence that several shells of gas had been puffed out around the star. The luminosity appeared to be high, signifying a much larger radius than the Sun's. I measured the star in 1970 in the infrared region of the spectrum and found significant energy was being radiated at these long wavelengths. It is difficult to be certain, but the infrared data suggests a rather dusty envelope surrounding the star, a structure known to characterize young objects. Some theoreticians had argued that in the very earliest phases of the birth of a star, it was possible to increase the luminosity of a young star substantially and abruptly. Their arguments were based on computer models for the collapse under gravity of a big cloud of gas and dust. Ultimately, this would lead to sufficient central squeezing of material that nuclear fires were ignited and a star was born. Things generally happen very slowly in astronomy. Only in early evolution do phenomena occur on "rapid" time scales, typically thousands or tens of thousands of years. To yield a flare taking only about one hundred days really taxes even the theoreticians, but it seems to be one more piece of (weak) evidence in favor of a "young interpretation" for FU Orionis.

Matters halted there in about 1970, with FU Orionis just another peculiar astronomical object in a class by itself. But the sky dictated otherwise: about two thousand light-years away, in the direction of Deneb in the constellation Cygnus, lies an interesting mess of bright glowing gas clouds and dense, dark dust patches. Photographs reveal bright and dark patches organized into a beautiful facsimile of the North American continent. In the dark clouds of the North America Nebula, a number of young stars were recognized in the 1950s. One star, found by a Lick Observatory survey of stars showing bright hydrogen lines in their spectrum, lies in a particularly filthy and opaque cloud.

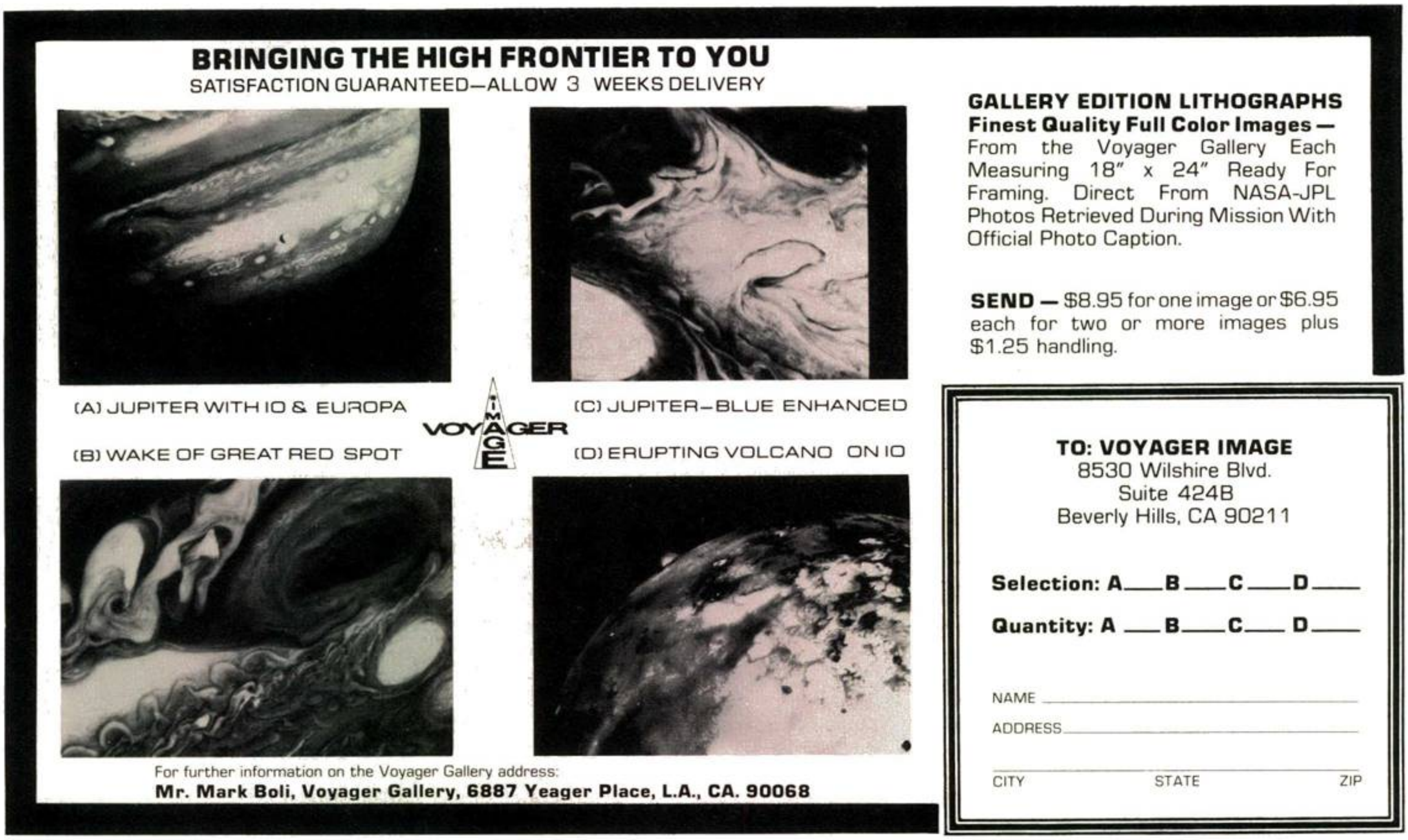
In late 1969 this object, designated V1057 Cygni (the 1057th variable star noted in Cygnus), flared from sixteenth to eleventh magnitude, taking about a year to complete the entire rise. This fact was not widely publicized and word only reached the (astronomical) world by spring of 1971. I observed the star in the infrared, for comparison with FU Orionis, and found it to be very bright at the longest wavelengths. Moreover, the infrared radiation showed broad spectral peaks, characteristic "fingerprints" of what are believed to be silicate dust grains. I continued to watch the star, as did a number of other interested astronomers.

V1057 Cygni has become noticeably fainter at optical wavelengths over the past few years but the brightness drop has still been less than two magnitudes. The infrared emission has also slowly diminished but the silicate fingerprints disappeared most rapidly of all. A reflection nebula appeared in the form of a broken ring surrounding the star, very similar to that around FU Orionis. Over the years this nebula has faded in response to the gradual stellar dimming, thus proving the picture to be a reflection. This time, however, a pre-flare spectrum does exist and it shows the object definitely was a young star, belonging to the class of T Tauri irregular variable stars, although its surface temperature cannot be determined.

After maximum, V1057 Cygni also showed a high luminosity spectrum but one somewhat warmer than FU Orionis had initially. The star has since cooled down to roughly solar temperature. Again there is evidence for shells of material expanding away from the star, perhaps remnants of the original stellar surface that were thrown off by an internal mechanism that we can only speculate about at present.

So then there were two! I spent the summer of 1971 vainly monitoring the other faint T Tauri stars in the North America Nebula, hoping that another young star would choose to flare. None did.

Astronomer George Herbig of Lick Observatory maintains an almost paternal watch on things of an early stellar evolutionary nature. Another star, V1515 Cygni, that lies in the dark clouds of a young stellar complex had come to his attention because of the photographic appearance of a wisp of nebulosity close to the star, and



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because of the brightness of the star in 1975 relative to his first view of it in 1954.

The past history of V1515 Cygni, as gleaned from collections of old plates, reveals a slow brightening from below seventeenth to about thirteenth magnitude between 1901 and the present. Most of the change took place over a twenty year period. It may well be that the star is still becoming brighter. It too shows an almost complete oval of nebulosity in modern photographs and definitely lies inside the dark clouds against which it is seen. In 1974 I found appreciable infrared emission from V1515 Cygni, indicative of warm local dust heated by starlight. The present spectrum in the optical region is almost solar in temperature, and of high luminosity.

There are clear similarities between all three stars here, although V1515 Cygni has been the most sluggish by far in its "flaring." After outburst, all the stars emerged with much the same type of spectral characteristics, and all revealed rings of reflection nebulosity in the dark clouds in which they lie.

The hunt is now on. Indeed another candidate fuor may have been found in a dark cloudy region on the borders of Lacerta and Cygnus. This star, however, has only achieved sixteenth magnitude even after it appeared unexpectedly in a dense dark cloud. Its classification as an FU Orionis star may yet be premature, although it does have a faint patch of nebulosity nearby and it does have appreciable infrared emission.

Two years ago I believed I had caught another candidate during its rise to maximum light. I cite this as an example of the unpredictability and perverseness of the most fascinating celestial objects. It rose from about nineteenth magnitude in 1955 to about thirteenth in 1978. But in the past six months it has plummeted in brightness and threatens to disappear from the sky once again! (As it turned out, this star displayed a spectrum rather different from the other candidates, so its exclusion from the class may not be so surprising.)

The direct attack on FU Orionis stars has proven difficult. It is now likely that a less aggressive method may yield better results in the long term. A Berkeley colleague, Leonard Kuhi, and I have just completed a massive optical and infrared study of some 500 young stars. In response to comments from the astronomical fraternity, one aspect of our work will be a catalog displaying the optical spectra of almost 400 faint young objects. We hope that when the next fuor flares, a spectrum of its pre-outburst state will exist among our collection of spectra of otherwise obscure stars.

Much is uncertain and speculative in the realm of these enigmatic stars. It's obvious that if adequate data were available on the nature of the pre-flare object, much more could be learned about the next fuor. We might then confirm our suspicions that these stars substantially increase their surface temperatures and expand their radii. It is very difficult at present to know if every T Tauri star undergoes a flare of this nature, or just those in a narrow range of mass. Herbig has even suggested that stars may flare recurrently, but his estimate of the period between the events in any one star offers little comfort to the observer, being about ten thousand years. In the past decade we have learned much about the formation and early life of the stars, largely through the combined efforts of radio, infrared, and optical astronomers, but there is so much yet to understand.

Perhaps in the "fuorture"...?

Martin Cohen Univ. Calif., Berkeley

I'm Not Worried...

Do not fear for astronomy! The solar power satellites envisioned by scientific grantsmen will never come about. (For background see ASTRONOMY, March '79, page 60, "Solar Power Satellites: A Threat to Astronomy!") Neither one — nor fifty — of these animals can be constructed in geostationary orbit in any foreseeable future. Why? A few reasons follow:

1. Each photovoltaic (solar cell) power plant is considered to consist of $32 \text{ x } 10^6$ square meters of active power collecting area, about 12.4 square miles. The output of known solar cells is about 152 watts per square meter at one AU from the Sun (outside the atmosphere, of course). The power available for conversion to radio energy is pretty astronomical, about $4.86 \text{ x } 10^9$ watts. (New York City requires about $8 \text{ x } 10^9$ watts.) Space-qualified solar cells cost, let us say, \$53 per watt. The photovoltaic array will therefore cost $\$53 \text{ x } 4.86 \text{ x } 10^9 = \$258 \text{ x } 10^9$ (258 billion dollars)!

At this point the reader should bear in mind a few facts:

First, solar cell power is one of two alternatives used for powering spacecraft. (This is considering long missions such as planetary exploration or communications satellite spacecraft.) The other alternative is small nuclear power plants which we and the Soviets don't like to use because of the physical and political fallout possibilities. Solar cell power is a pretty small portion of the cost of scientific or communications spacecraft.

Second, solar cells aren't born by immaculate conception, i.e., they are manufactured. Most rugged and long-life (in space) solar cells are based on very pure silicon. This is the silicon of silicon dioxide, one of the most locked up, refractory compounds commonly found on our planet. It takes about as much energy to separate, super-refine, and place additives in silicon for solar cells as they are expected to collect in ten years.

2. Solar cells weigh in at around one kilogram for each 11.9 watts of power output. The total mass — or weight on Earth — of the above mentioned array will therefore be about $400 \text{ x } 10^6$ kilograms. This is something like 400,000 tons or 800 million pounds.

Now let's put this into orbit. The most hairy machine I know is the Saturn V which can be rigged to put 100 tons on the road. This works out to be 4,000 missions worth of Saturn boosters. I'll leave it up to you to work out how many tons of fuel (old hydrocarbon kerosene) and liquid oxygen will be used, but please allow me to sit in at the negotiations for this fuel with neighboring and foreign heads of state.

Riddle me no mad thoughts my friends! We will not use fusion power to orbit this horror. If we have fusion power, what would we need the power satellite for?

Again the reader should bear this in mind: in all of the above figuring I have rounded off favoring Solar Powered Satellites (SPS). That is to say there has been no allowance made for supporting structure, station keeping, or aiming devices. In the following, however, I must invoke some practicality.

3. The great power in orbit will be converted into radio waves for transmission down to Earth. The only gross way of converting direct current power to radio waves on a large scale is by old-fashioned vacuum tubes. These vacuum tubes are the thirty-second cousins to the tubes in that old T.V. set you have in the rumpus room. One kind of such tube is called the platinotron. The platinotron is a sort of crossbreed between the magnetron and the klystron. If we assume the beam-down frequency to be around 2,450 megahertz, this kind of tube can be fairly efficient as such converters go. Let's pretend that space qualified tubes of the above kind can be made with a power output of 475 kilowatts each at an efficiency of 70%. Pretend further that such tubes with an integrated antenna could be made to weigh 1,000 kilograms each or about a full ton. This means that only $3.4 \text{ x } 10^9$ watts of the available $4.86 \text{ x } 10^9$ watts will be turned into radio energy. So at 70% efficiency, something like 7200

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tube/transmitter/antenna assemblies will be required — a piddling sixteen million pounds of hardware. Crank up more Saturns. We have just begun to fight with reality.

In case you have been wondering, and I'm sure you have, what happens to the 30% of energy lost in the transmutation of the solar cell power to radio waves..?? This energy appears mostly as heat: good old-fashioned warm. Now heat/warm is pretty easy to get rid of on Earth — plug in a fan to cool your radio tubes or in extreme cases, plug in the water supply. Water-cooled tubes are very much in fashion in larger radio and radar transmitters. However, when you are out in space, it's not so easy to come upon a source of water or convenient atmosphere to blow over your tubes. (No offense meant.) You have to dump the heat by radiation, and what's more, by radiation upstream, so to speak, against the normal heat flux furnished by our favorite star Sol. I won't go into how many square feet/meters of radiator will be necessary to get rid of 1.5 x 10^9 watts of waste heat generated by this array of high power tubes.

4. There are also a bunch of tedious facts associated with radio power generation that could possibly be put in the form of more "bear in minds" but which are so serious that I will make separate items out of some of them.

First: Efficient power generation tends to be of the pulsed kind. Thermodynamics gets involved and, sort of guilt-by-association, electrodynamics. A diesel engine pulsing at a two or four cycle repetition rate is much more efficient than a turbine engine. The reason is that the diesel pulses of power involve singularly higher differential temperatures than a turbine can withstand on a continuous basis. A radio frequency power generator is most efficient in a pulsed configuration. Let's face it, the only (technically) efficient device in your television set is the horizontal sweep generator. It is a pulsed device. Incidentally, it operates at a frequency of about 15 kilohertz, a low radio frequency. This electrical pulsed effort is known technically as Class C operation. Class C operation is, in the limit, 100% efficient. That is, where the pulses are of zero width but hugemungous in amplitude.

Second: By an act of Nature, pulses contain higher harmonics or multiples of the source frequency of the pulses. In the diesel engine, the higher frequency energies are mostly smoothed or integrated into the whole power by the flywheel on the engine. The flywheel may be favorably compared with the tuned or "tank" circuit on the output of an efficient electronic power generator. No flywheel or tank circuit is perfect, of course, so harmonics which aren't smoothed are allowed to sort of hang out. These left over harmonic energies comprise much of the sharp noise or rattle in a diesel engine at idle. In the electronic analog, the harmonic components inherently involved in the use of a Class C power source appears as radio interference at whole multiples of the source repetition rate/frequency.

Remember I said the frequency of the horizontal sweep system in television receivers was near 15 kilohertz, 15,750 Hz to be more exact. If I light up my shortwave radio to listen to the popular 25 meter shortwave band (around 12 megahertz), I find a noise band every 15+ kilohertz; this is the phase-incoherent summation of stray emission from all of the television receivers in my apartment building. It's a sure thing, therefore, that harmonics to the order of 12 MHz divided by 15,000 Hz exist, that is to the harmonic order of 760.... In my work I have chased the harmonics of a "totally enclosed" 40 megahertz power oscillator to 960 megahertz, or the 24th harmonic.

Now I will return to our mythical orbiting power generator of some 3500 million watts at, say, 2450 megahertz. Let's try for the twenty-fourth harmonic: this will be at 58.8 gigahertz. Of course the power at this harmonic will be a small fraction of the power of the fundamental, but the power of the fundamental is so damned big that I expect very careful design to lead to only 20,000 watts at the second harmonic and progressively less at each higher harmonic. Now we can be very glib about only 20,000 watts (2nd harmonic) but this energy will go somewhere. That somewhere is down-link to Earth. Twenty thousand watts is more power than the total of all space-to-Earth transmitters at all frequencies have ever radiated. This will not only put out the receivers of the radio astronomers, but will put out the use of the communications frequencies over half of planet Earth — and that's not even considering what the scattered or uncollectable power from the 3 billion watts at the fundamental 2450 megahertz will do. This will be so gross a blast of raw energy that it might cause the receiver input circuits of all radio astronomers, and radars and communicators to light up like Christmas trees.

5. There are rules. Radio transmissions which may cross national boundaries fall under the cognizance of the International Telecommunications Union (ITU). The ITU is officially a branch of the United Nations as for example is the World Health Organization. Frequencies are allocated for the use of participating nations. Permissable power-flux-densities for high frequency transmissions are assigned by the radio technical arm of the ITU called the International Technical Consultative Committee (CCIR, from the French words meaning the same). The ITU is a "one vote for one nation" assembly. That is to say Haiti and Yemen have the same power, by vote, as the United States and the Netherlands. (Some technical whimsy occurs because of this situation. Some land-locked nations have maritime channels allocated in maritime communications bands.) In 1974 the United States, via NASA, launched a "high power" satellite (ATS-6) to test some aspects of television broadcasting from geosynchronous orbit. The 15 watt (or cigarette lighter power) down-link transmitters were carefully tailored to spread their power over about 50 megahertz of the spectrum. In this way we lived up to the letter of the ITU regulations on space-to-Earth power-flux-density. The frequency used was quite near that generally considered feasible for the SPS down-links.

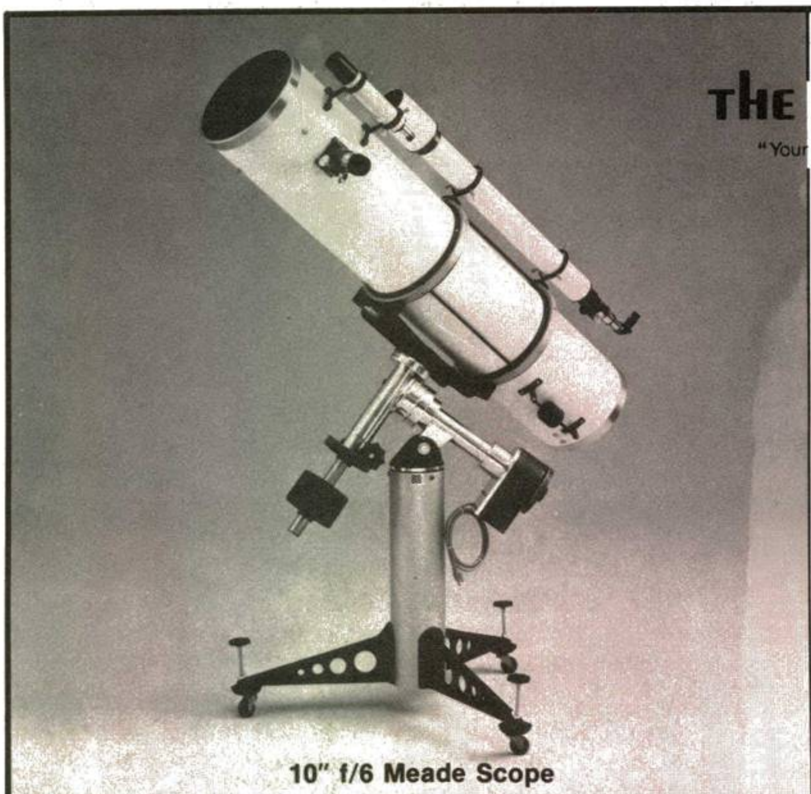
Can you imagine what the reaction, after laughter, of the assembled ITU and CCIR would be to a proposal to beam down on the order of a billion watts?

6. Here I will take the defensibility of an SPS under my perusal. The United States has landed robot missions on Mars. The Soviet Union has recovered moon samples by remote mechanical operations. I submit that in a very few years at least seven nations will be capable of messing up any device in space having a fairly predictable orbit. Friends, I am not thinking of atomic bombs, rather about large nudges by either rockets or conventional explosives. No nation could afford to be dependent on such an exposed and vulnerable energy supply.

7. I could comment on an interesting idea I read concerning the fabrication of the super magnets for the orbiting electron tubes. The author said these hundreds of tons of magnets will be made of samarium-cobalt alloy. The present production of samarium (a rare earth) is measured in pounds per year, and cobalt is a very important metal obtained from outside the United States.

It is unfair to criticize without offering a practical alternative. My radio astronomy underground tells me there is a radio source in Cygnus which emits radio waves — 10^{38} watts. So all we have to do is move the solar system to less than ten light-years from this object and put antennas on our homes and autos.... Of course, Yankee ingenuity and a few unemployed aerospace engineers can work out the details of the 300 light-year trip.

Hal Halvorsen Silverspring, MD



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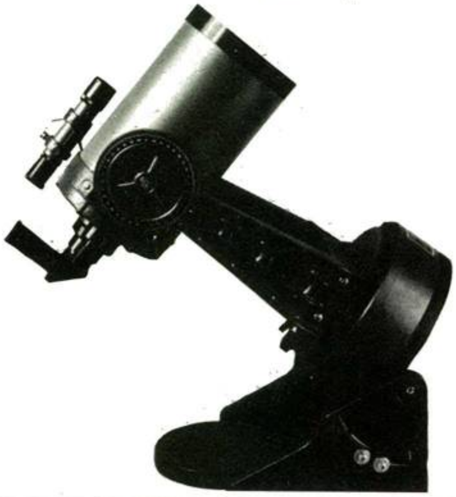

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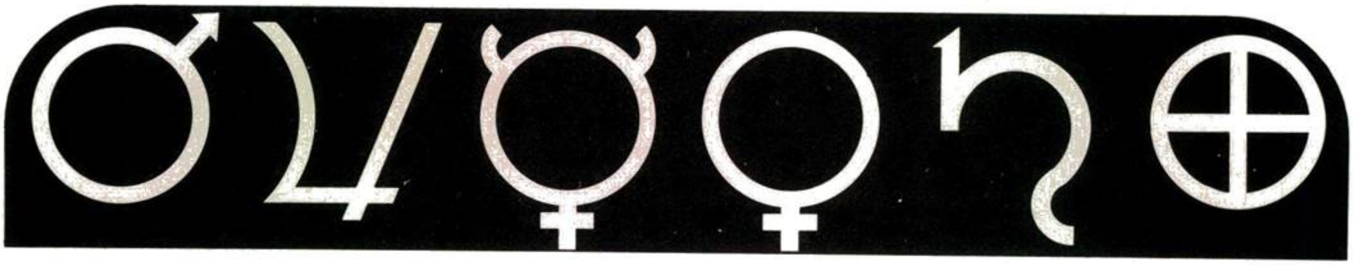


Mercury Meets Jupiter

Many people become summertime stargazers, if only because they're away from the city on vacation and thus get to see a really dark sky. And the heavens over summer campsites can be splendid indeed: the Milky Way is well up and prominent, with its central portions in Sagittarius poking over the southern horizon; Cygnus, Lyra, and the Summer Triangle move majestically overhead; and the stars seem close enough to reach out and touch.

This July, the naked-eye planets are all either evening or dawn objects, in contrast to the past few months. You'll find them easy to locate and there'll be some pretty conjunctions — good photographic subjects.

Mercury

In last month's issue, we ran a diagram you may want to refer back to giving Mercury's path during June and July relative to the western horizon just after sunset. Its visibility won't be as good this month as last, but even the rawest beginner should have no trouble locating it.

During July's first two weeks, look for Mercury just to the north of due west. It will be low, about 10° high, and of magnitude +0.7. (The short side of a paperback book held out at arm's length will approximate 10°.) Big, bright Jupiter will be shining above it and somewhat to the left. Because the planet's elevation isn't any too great, you may have to find a field or lake to look out over in order to get the requisite low horizon.

Mercury never strays too far from the Sun because its orbit lies far closer than Earth's to that luminous body. But at periodic intervals, it wanders out to the east or west of the Sun, permitting you to catch sight of it for a couple of weeks. One such apparition is happening now; on July 3rd Mercury will be at so-called greatest eastern elongation, when the little planet will be at its farthest distance to the east of the Sun. On this date also, it will be about a degree south of the Beehive star cluster. A pair of binoculars will reveal Jupiter and the cluster together with Mercury, an attractive sight.

Because Mercury orbits close to the Sun, its motion is very rapid: starting at the beginning of the month, go out every clear night and see how quickly its positions alter. By the 31st, Mercury will have moved into position between us and the Sun and will be invisible to the naked eye.

Venus

Earth's so-called "sister planet" — a misnomer if ever there was one — is now nearly as far from us as it can get. Months ago, back in November of last year, it passed between the Earth and the Sun. Ever since then it has been drawing slowly away from us as it heads for the far side of the Sun. Late next month it will be directly in line with the Sun as seen from Earth: this is superior conjunction. Until then Venus will remain in the morning sky, rising ever closer to the Sun each day.

Venus is quite bright, -3.3 magnitude, but its proximity to the Sun makes it hard to find. As you did with Mercury, put yourself in a place where the view of the horizon is good, but for Venus look to the east. Half an hour before sunrise, you'll see it about 5° high in the east-northeast.

Earth

On the 3rd, coincidental with Mercury's elongation, Earth will be at aphelion, its farthest distance from the Sun. The actual distance will be 1.0167+ astronomical units, or about 2½ million km beyond the "average" value of 149.6 million km.

Mars

Venus' companion in the dawn sky is the red planet, Mars. Though it's a lot dimmer than Venus, Mars is so much farther away from the solar glare that it won't be very hard to find. Around the first of July, half an hour before sunrise, look for a magnitude +1.5 object a little to the north of east and about 20° high. By the end of the month, the elevation at the same time of day will be over 30°, while its direction will have remained about constant.

Mars is in the zodiacal constellation of Taurus and will pass 5° north of the first magnitude star Aldebaran on the 10th of the month. Sweeping through this area with binoculars is very enjoyable, as their wide field of view will show you several objects together.

Mars' tiny size means that it never gets very large in a telescope, even though at its closest it comes relatively near. The times of nearest approach are called oppositions, and the next one for Mars happens in February of next year. But not all oppositions are alike: Mars has one of the most egg-shaped of all planetary orbits and so the opposition distance varies regularly over a 15-17 year period. The last "good" (close) opposition was in 1971; the coming opposition will be the worst one for the current cycle.

Jupiter

The king of the planets becomes lost in the evening twilight during this month as it is engulfed by the bright glare of the Sun. In the section on Mercury we mentioned that you'll see the two close together in the west

The setting Sun reveals the manifold details in Mare Imbrium. At right center the arc of the Apennines curves towards Copernicus, while at left center gleam the pale markings of Aristarchus. Photo by John Asztalos with a 12" reflector at f/20. He used ASA 64 slide film exposed ⅛ second.

during the first two weeks of July. Don't let the opportunity slip, for thereafter they'll both be sinking swiftly toward the horizon.

Saturn

The most distant of the naked-eye planets, ringed Saturn lies in the middle of the constellation Leo. As with Jupiter last month, so it goes with Saturn now: get in your observations while you can, for next month Saturn too will disappear into the bright evening twilight.

The easiest way to identify Saturn is to go outside with June's Star Dome map and find Leo. In the south central part of the group you'll find a brightish "star" that isn't on the chart. This is Saturn. (You should use last month's map because Leo is setting early and July's map shows it on the western horizon.)

You may also be able to find it because it doesn't twinkle as do the real stars. The reason planets don't twinkle and stars do is simple. Stars are point sources of light; they are so distant they appear to have no physical size. Planets on the other hand are close enough to have measurable sizes, at least through a telescope. As light from a star passes through our atmosphere, the unsettled air bends and distorts the light. And since the starlight is only a point, it moves and appears to flicker.

When light from a planet's extended disk traverses the air, each point making up the image is also distorted just like a star's, but because there are many points in the image, the effect averages out to give a steady light.

If you look at Saturn through a telescope hoping for a glimpse of the famed rings, you won't be seeing too much. Right now, the rings are tilted at a very shallow angle (5½°) to our line of sight. In a small scope, they'll be hard to see. The rings will continue to grow thinner in appearance until late October when they'll be edge-on to our view, and become invisible.

Uranus

Uranus was the first of the "modern" planet discoveries: William Herschel found it during one of his telescopic sweeps in 1781. It caused a sensation at the time because it was the first new planet added to the solar system in recorded history.

Uranus actually comes within the limits of naked-eye observation, but always stays very dim, being around 6th magnitude. After astronomers first computed its orbit, they found on looking through old observation records that the planet had been seen prior to its discovery on several occasions. But at each such observation it had been taken for just another star. When you finally locate it, you'll understand how easily this may have happened.

This gas-giant planet is currently in the constellation Libra, and is only a degree or two away from Libra's brightest star, Alpha (α). (Alpha Librae is marked on this month's Star Dome.)

If you have a pair of binoculars, point them at Alpha, placing the star on the right side of the field of view. Uranus will be a small point of light (among several!) at about right center. If you have a telescope, use your low power eyepiece and train the scope on Alpha. A little over 2° to the east-southeast of Alpha, you'll pick out the dim disk of the planet, 3.9 seconds of arc in size. Higher powers will show you the disk more clearly. Binocular users will have to observe the field of stars for a couple of weeks to find the slowly moving dot that's Uranus.

Neptune

Neptune, discovered in 1846, is another gas giant and, so far as we know, very similar to Uranus. Like Uranus, Neptune also had several pre-discovery observations, and these early sightings greatly helped astronomers refine its computed orbit by giving them a lengthened time line of observations.

You can find and follow Neptune with binoculars, but it's harder than with Uranus. The planet is dim (8th magnitude) and being farther from the Sun, it moves more slowly. Since you locate it by its motion, you'll certainly have difficulties. However, a telescope owner can tell it from a star by its visible disk, just 2.5 seconds of arc in diameter.

The place to look is about 10° to the east-northeast of Antares, the ruddy eye of Scorpius. Neptune is in Ophiuchus, near the 4th magnitude star Xi (ξ) Ophiuchi. Sweep 10° east of Antares and 3° or 4° north. Neptune should be in your low power field of view. Neptune's motion is almost east-west, and over the course of July, will shift its position by ¾° in a westward direction.

Meteors

In July there are only two showers, neither of which is particularly outstanding: the Delta Aquarids, peaking on or around the 28th, and the Capricornids, which peak two days later. Both of these meteor streams are diffuse and you'll spot activity from them over many days. The Aquarids show about 20 per hour, the Capricornids 10.

The equipment for meteor watching is simple, just your two eyeballs. The only drawback is that you should be looking between midnight and dawn for best results. This happens because the meteor activity falls heaviest on the "leading" hemisphere of the planet in its orbit around the Sun. After local midnight you rotate onto the leading side of Earth as it plows through the meteor stream.

The technique is equally easy: get yourself a comfortable chair, wrap up in a coat or blanket, and sit facing the sky; the name of each stream tells you the constellation or part thereof where they'll appear. As the hours pass, you may also see auroral activity, an added plus to the meteors.

Universal Time

Astronomers the world over use an unambiguous system of time reckoning based on a 24 hour clock, called Universal Time (UT). Times given in Sky Almanac are in UT unless noted otherwise. To convert UT into your local daylight time, subtract the following number of hours for each time zone: EDT, 4; CDT, 5; MDT, 6; PDT, 7; Alaska and Hawaii, 9. For example, if an event is to happen at 03:00 hours UT on June 7, then the time in EDT would be 11 p.m. June 6. Likewise, 03:00 UT on Sept. 2 becomes, in PDT, 8 p.m. on Sept. 1.

Lunar Phases

First quarter: July 2, at 15^h24^m UT, in Virgo. Full Moon: July 9, at 19^h59^m, in Sagittarius. Last quarter: July 16, at 10^h59^m, in Pisces. New Moon: July 24, at 1^h41^m, in Cancer. Perigee: July 11, at 12^h. Apogee: July 27, at 0^h.

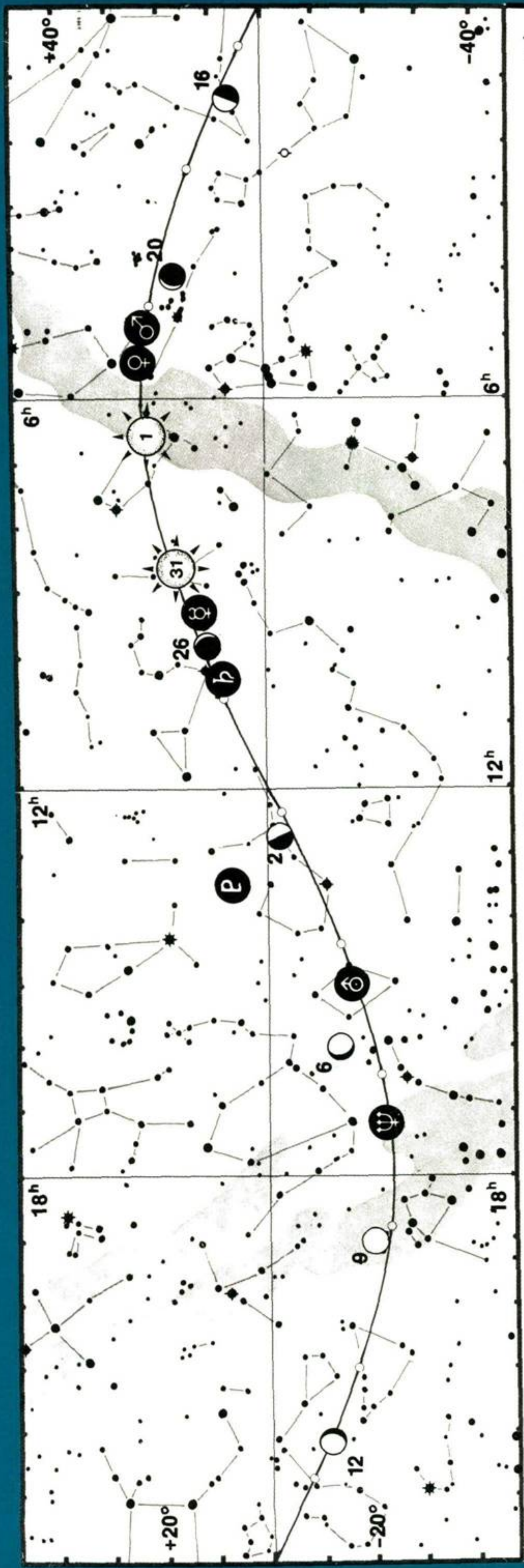
August Previews

1	First Quarter Moon
7	Full Moon
12	Perseid meteors
13	Jupiter in conjunction with Sun
14	Last Quarter Moon
18	Mercury: greatest western elongation
22	New Moon
25	Venus: superior conjunction
30	First Quarter Moon

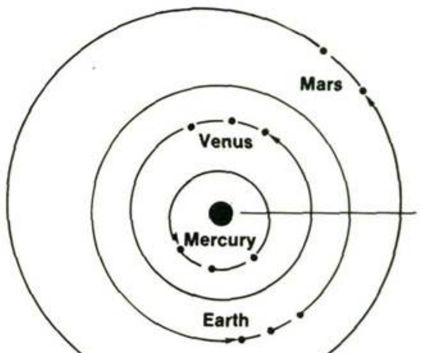
The most exciting astronomical event for August comes during the first part when you'll see the annual return of the Perseid meteors. The shower rises to peak activity quickly, but you can be watching for them from the beginning of the month. The Moon will interfere a good bit with this year's show, however.

Planet Finder

July 1979

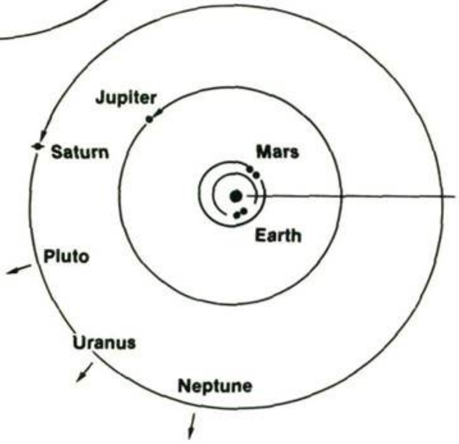

+40°
-40°
16
20
6h
6h
1
31
26
12h
12h
2
6
18h
18h
9
12
+20°
-20°

The Planets in Their Courses


Mars
Venus
Mercury
Earth

The positions of Mercury, Venus, Earth, and Mars in their orbits are shown for the beginning, middle, and end of the month. (Mars for the beginning and end only.) The vernal equinox is the line at right.

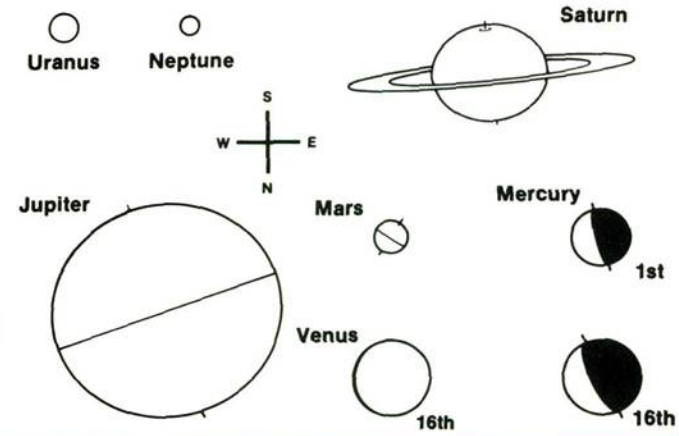
The orbits of Earth, Mars, Jupiter and Saturn are shown at right. Earth and Mars' positions are for the first and last of the month; Jupiter and Saturn for midmonth. The outermost planets' directions are indicated.


Jupiter
Saturn
Mars
Earth
Pluto
Uranus
Neptune

Positional Data

Planet	Date	R.A. (1979.6)	Dec.	Mag.	Distance (AU) from Earth	Distance (AU) from Sun
Mercury ☿	5	$8^h 42.6^m$	18°01.0′	+0.8	0.82	0.45
	15	$9^h 03.4^m$	14°14.3′	+1.4	0.68	0.47
	25	$8^h 54.6^m$	12°41.3′	+2.4	0.59	0.45
Venus ♀	10	$6^h 19.3^m$	23°21.6′	−3.4	1.68	0.72
	30	$8^h 05.1^m$	21°06.5′	−3.4	1.71	0.72
Mars ♂	15	$4^h 47.6^m$	22°21.6′	+1.5	2.12	1.47
Jupiter ♃	15	$9^h 05.3^m$	17°22.2′	−1.3	6.26	5.33
Saturn ♄	15	$10^h 51.1^m$	9°17.5′	+1.4	10.01	9.37
Uranus ⛢	15	$14^h 58.4^m$	−16°35.7′	5.8	18.24	18.70
Neptune ♆	15	$17^h 09.5^m$	−21°29.1′	7.7	29.43	30.28
Pluto ♇	15	$13^h 25.6^m$	9°27.0′	14.0	30.29	30.23

Telescope View


Uranus
Neptune
Saturn
S
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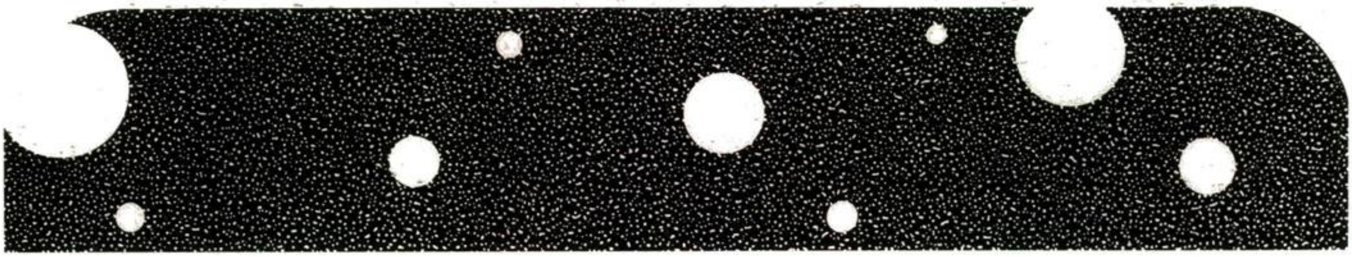
Jupiter
Mars
Mercury
1st
Venus
16th
16th



Does Cosmology Have a Future?

by

Dewey Schwartzenburg

Is the universe infinite? How did it begin? Will it come to an end, and if so, what will that end be like? What is the ultimate architecture of the universe, and how do its most fundamental constituents give rise to that structure? Are there other universes, or is ours unique? For that matter, is the universe rationally comprehensible at all, or does reality ultimately transcend our feeble human understanding?

These are the amazing questions that modern cosmology seeks to answer on a mathematical, scientific basis. Cosmology, once the stepchild of physics and astronomy and all too often regarded as the black sheep in the family, has now become a booming field of energetic and creative scientific thought. But the latest research and thought in the field of cosmology has raised new and profound questions that challenge the very foundations of modern science. If cosmology has a future, it is beginning to be apparent that a number of major new breakthroughs in our understanding of ultimate reality are now necessary. On the other hand, it may be that we are finally encountering the ultimate limits of scientific knowledge.

Philosophy and Science

Mankind has always wondered about the ultimate nature of the universe — its origin, its overall structure and workings, and its final goal. But until this century the answers to such cosmic questions were outside the province of scientific investigation. Such answers as were available were largely speculations or assertions of philosophy, religion, and myth. Sometimes, especially toward the end of the last century, great schemes to account for ultimate reality were advanced by various scientists, but, as philosophers of science soon pointed out, the scientist-authors of these grand designs were acting more as philosphers than as scientists. That is, their ideas were more or less rife with scientifically unfounded assertions, philosophical assumptions, and gaping methodological holes.

This has always been the greatest danger for scientific cosmology, the science which more than any other touches upon issues and questions of deep philosophical and even religious significance. In cosmology, one always wonders which comes first, the chicken of philosophy or the egg of science? To what extent does a cosmologist's philosophical predilections influence his science, and, on the other hand, with what validity can philosophical concepts be extracted from the theories and equations of science?

It is now recognized, for example, that even Newton's work was flawed by certain theological concepts which led him to postulate the concept of "absolute space." Even before Albert Einstein tossed absolute space into the dustbin of unfounded assumptions, philosophers of science (such as Henri Poincaré and Pierre Duhem) had realized that it had no scientific basis. Einstein, in a sense, merely had the courage to work out what would happen to physical laws if the empirically meaningless idea of absolute space were eliminated — and in 1905 he came up with the Special Theory of Relativity.

Einstein also turned out to be the founder of the modern science of cosmology, the truly scientific study of the overall structure of the cosmos. In fact, he was practically forced to found cosmology. The Special Theory of Relativity dealt with the structure of space-time as totally independent of the presence of matter within it. In essence, Special Relativity provides a model of an *empty* universe, one containing no matter at all. Unfortunately that's not very relevant to the real universe, so in his General Theory of Relativity of 1915, Einstein advanced a mathematical model for the structure of space-time as related to the presence of matter. But in order for this model to deal effectively with any part of the real world, it turned out that the equations of General Relativity had to be solved for the whole world, that is, they inevitably led to a model for the entire universe.

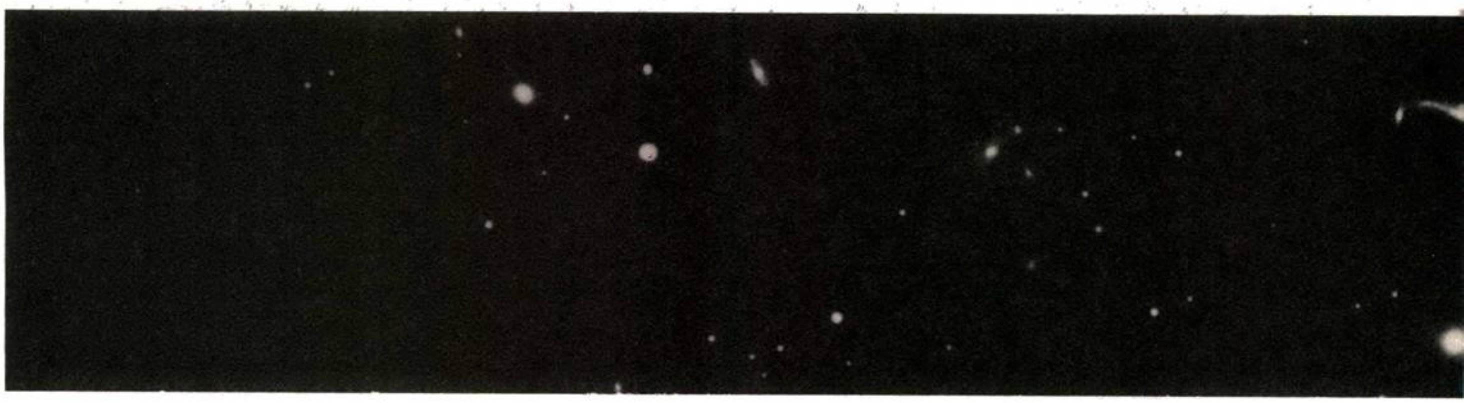
It was Einstein himself who, somewhat hesitantly, took this momentous step in 1917 when he published what is generally considered to be the first paper in the modern science of cosmology: "Cosmological Considerations on the General Theory of Relativity." In it he presented the first complete mathematical model for the entire universe, a model well-known ever since in cosmology as the "Einstein universe," even though he soon rejected it himself.

The Einstein universe was flawed because, in one of the great ironies in the history of science, Einstein fell into the same trap as Newton. He allowed his philosophical ideas to intrude on his theories. Einstein was not alone among scientists of his time in seeing the universe as static and eternally unchanging, but he soon discovered that General Relativity would admit such a static universe only if an additional term, the *cosmological constant*, were introduced into the equations. In reality, the cosmological constant was nothing more than a philosophical intrusion into an otherwise complete and self-consistent mathematical structure, and Einstein later called this meddling with his own equations the greatest mistake of his life.

Without the cosmological constant, General Relativity leads to a model of a non-static universe, in particular, one which is expanding. This was first noted in 1922 by Alexander Friedmann, and it is one of the great achievements of General Relativity that the so-called *Friedmann solutions* actually predicted that the universe was expanding before Edwin Hubble and Vesto Slipher discovered that fact observationally.

Robert Jastrow has pointed out in his recent book, **God and the Astronomers**, that for years scientists felt philosophically uncomfortable with the expanding universe because it implied there must have been a "beginning" (the so-called Big Bang). And Fred Hoyle has explicitly admitted that it was his philosophical revulsion to such a beginning which led him and a few colleagues to develop and expound their "steady state" model of the universe in the 1950s.

Science has never been as pure and free of philosophical influence as scientific popularizers would have us think, but the safeguard has always been scientific method. Moreover, modern philosophers of science point out that the claims of science on ultimate truth are not as far-reaching as many nonscientists today believe. The scientific method is a powerful means of achieving objective, useful, and verifiable knowledge, but even it itself is founded upon certain philosophical principles (such as the one which denies "real existence" to phenomena non-observable in principle) which may be debatable on other grounds. It is especially important to bear this all in mind when considering the findings and speculations of modern scientific cosmology, fascinating though they are philosphically.



Physics Confronts Singularities

"Ladies and Gentlemen! In this corner, undefeated at 6 feet 4 and 250 pounds: Modern Physics! And in the opposite corner, also undefeated in every match, of zero size with absolutely no spatial extension, but weighing in at infinite mass: The Naked Singularity!"

Perhaps the most significant philosophical underpinning of modern science is the assertion that nature is, in the final analysis, rationally comprehensible. After all, if it is not, there is little point in seeking to explain and understand it. But in confronting singularities, physics today finds itself faced, right on its own home ground, with the utterly incomprehensible.

The great irony is that modern physical theory inevitably led itself to such a confrontation. In the late '60s, a number of cosmologists (among them Roger Penrose and Stephen Hawking) proved mathematically that if General Relativity is in fact correct, the universe must contain at least one *singularity*, that is, a point or event in space-time where the laws of physics cease to apply. At a singularity, all physical laws vanish or become meaningless. General Relativity thus predicts its own downfall — as well as that of the rest of science.

Needless to say, singularities make physicists singularly uncomfortable. In a sense, they're a sign either that present physical theory is incomplete, or that nature is ultimately beyond rational understanding. Both possibilities are unpalatable, but for the present scientists must be content to work around the singularities, so to speak, until some better theory which can eliminate them (or deal with them) comes along.

The chief singularity of modern cosmology is the "primordial nucleus" of the Big Bang itself. At the initial point of the Big Bang, physical laws have no validity. Although modern physics is capable of dealing with conditions within millionths of a second of the initial expansion of the universe, science falls silent about a universe younger than billionths of a second and smaller than an atomic nucleus.

In recent years, other singularities arising out of modern relativistic cosmology have appeared to confound theorists. In particular, black holes are considered to contain singularities at their centers, but there, at least, it was thought that a sort of "cosmic censorship" protected the rest of the universe — including earthly scientists — from the embarrassment of a singularity. The consequences of a singularity's existence inside a black hole are minimized by the scientific principle mentioned above that if a phenomenon is in principle unobservable, it can be dismissed as having no physical reality. As one philosopher of science put it, "Black holes may have no hair, but things get pretty hairy inside 'em!"

Unfortunately, Stephen Hawking, in the process of exploring possible quantum gravity theories, found that black holes eventually "evaporate." The larger the black hole, the longer it will take for it to shrink away by radiation to nothing, but if the time is long enough, all black holes will eventually disappear — as black holes, that is. But the singularity will remain, now unshielded from the rest of the universe by the black hole's event horizon. Such a singularity is known as a *naked singularity*, and the idea of a universe containing naked singularities wandering around loose is enough to make even strong physicists weep.

At present it is not even known for certain that black holes actually exist (though that seems more and more likely), and recent evidence suggests that there are very few, if any, primordial microscopic black holes currently "evaporating" out in space to leave behind naked singularities. But merely the fact that current theory predicts such things raises questions about the ultimate ability of science to account for reality — in the classic formulation, "to save the phenomena."

Eternity May Be Unstable

Naked singularities may even ultimately bring about total chaos in the whole universe. If the expansion of the universe does not eventually slow down and turn into a collapse — and it appears likely it won't on the basis of all the latest evidence — we might suppose that the expansion will simply continue forever, with the average density of the universe always declining.

But something much worse than this picture of an eternally unwinding and dying universe may come to pass. John Barrow of Oxford University and Frank Tipler of the University of California, writing recently in **Nature**, noted that black holes will eventually swallow up all the matter in the universe. Then, as Stephen Hawking discovered, the black holes themselves will finally evaporate over an unimaginably long time, releasing equal amounts of matter and antimatter. The matter and antimatter will suffer mutual annihilation, leading to a universe without matter at all, containing only radiation. What's more, the evaporation of all those black holes will leave behind naked singularities, and according to theory, the orderly structure of space-time suffers a complete breakdown even in the vicinity of a singularity. It also becomes meaningless even to speak of "eternity," because time itself, rather than continuing or even just ending, will become so twisted and chaotic that causality and the possibility of change are destroyed.

Thus, according to these theorists, the ultimate end of the universe will be a state in which matter has ceased to exist, space and time are torn and distorted out of meaning, and even the large-scale architecture of the universe, which now seems to be so symmetric and ordered, is reduced to utter and final chaos. Not only will the house of cards collapse, but the cards themselves will be torn to shreds and hopelessly scattered. "Reality" seems destined for self-annihilation.

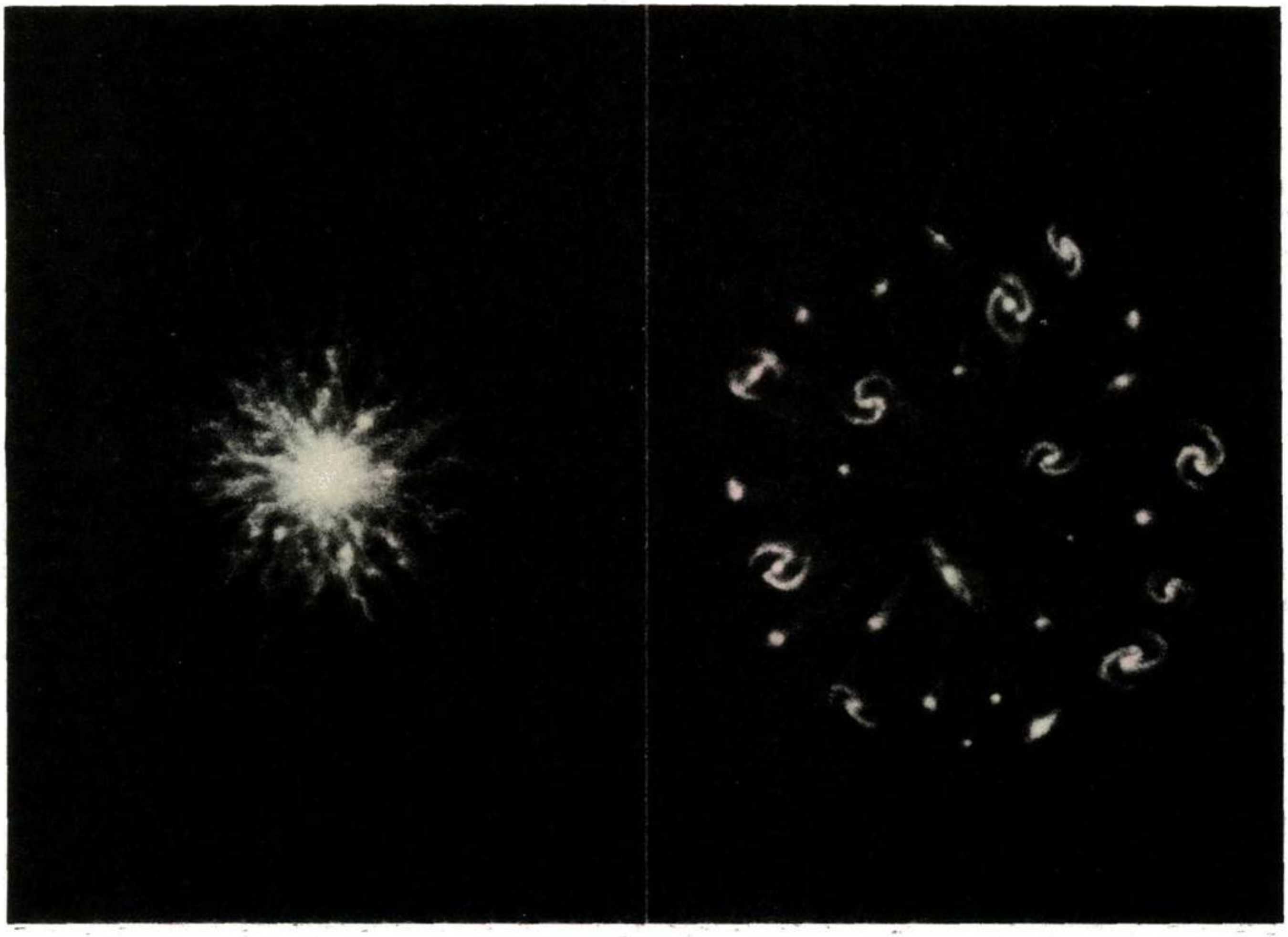
The Anthropic Principle

If the end of the universe is to be total dissolution and chaos, where did all the present order come from? This has been a particularly distressing problem for cosmologists, for every time a theorist has proposed a mechanism for automatically bringing order out of an initial chaos, chaos has slipped in by a back door (in the form of another theorist's theory) and wrecked the mechanism. One problem in particular is to explain why the universe is so *homogeneous* and *isotropic*. Isotropic means that the universe is symmetrical, and looks pretty much the same in whatever direction we look. Homogeneous means that the "stuff" in the universe seems remarkably evenly spread out. If the Big Bang had only spit out black holes instead of a rather smooth distribution of matter, we wouldn't have much of a universe to live in. Why didn't it? And why is the universe so symmetrical in all directions? No satisfactory solution has yet been found.

To make matters worse, it now appears that if the fundamental physical constants which characterize the structure of the universe — constants whose values are essentially arbitrary and could possibly have been otherwise — were different by even the tiniest amounts, a very different universe lacking the complexity and structure (and potentiality for life) of ours would have been the result. Writing in the April 12 issue of **Nature**, Bernard Carr and Martin Rees of the Institute of Astronomy in Cambridge, England, calculated what would have happened in the universe if a number of fundamental physical constants had had different values from their true ones. They found that the possibility of life as we know it evolving in the universe "is in some respects remarkably sensitive" to the numerical values of these arbitrary constants.

Does all this mean that cosmology has come to the point of having to postulate a "Creator"? Not necessarily, but it does mean that at its present state of development, cosmology can account for the observable state of the universe only by invoking some sort of purely philosophical hypothesis. The currently favorable one is called the *anthropic principle*. Briefly, the anthropic principle merely states that if the universe were in fact different in any significant way from the way it is, we wouldn't be here to wonder why it is the way it is. In other words, we are here because the universe is the way it is, and the universe is the way it is, because we are here, and so forth.

If this seems philosophically unsatisfying to you — and you may be surprised to discover that it's quite satisfying to many theorists — it turns out that there is a way of interpreting the anthropic principle which is also a valid philosophical interpretation of quantum mechanics. Back in the 1950s, H. Everett suggested that the non-deterministic probability statistics of modern quantum theory could be understood in a novel way. He proposed that at each and every quantum mechanical event governed by probability, the universe "split" into two parallel universes, one in which the event took place and one in which it did not. Take a particular radium nucleus, for example. We know that there is a 50-50 chance that it will decay radioactively sometime within the next 5000 years or so, but there is no way, even in principle, that we can know whether it will decay in the next second or not. According to Everett's idea, there



The Big Bang which, according to modern cosmology, began our universe was apparently a very smooth, highly ordered, and symmetrical explosion. Accounting for the observed isotropy and homogeneity of the universe has long been one of the chief unsolved problems in cosmology. Art by V. Costanzo.

exist parallel universes, in each of which the radium nucleus decays at a different time, so that all possibilities actually do take place in reality somewhere. In one of those universes the decay takes place in exactly one second, while in the rest a greater or lesser time elapses. Obviously this quickly leads to an infinity of parallel universes, so that all possibilities and combinations of possibilities are covered.

The physicist John A. Wheeler has expanded Everett's idea to include an infinity of parallel universes each with different values for the fundamental constants. In the great majority of these, nothing "interesting" would ever happen —there would be universes without stars, and others without atoms, and still others without even matter. Only in those universes, such as ours, where conditions were just right, would life have evolved with cosmologists sitting around proposing such theories.

Thus the Everett-Wheeler interpretation of the anthropic principle provides a philosophically satisfying rationale for the peculiar character of our universe. But there is one hitch: such parallel universes, while a legitimate philosophical consequence of quantum theory, are totally unobservable, and their very existence is scientifically unverifiable. This leaves cosmology with an "explanation" which has no place in science in the first place. As Carr and Rees note in their paper, the anthropic principle "may never aspire to being much more than a philosophical curiosity."

The Future of Cosmology

Does cosmology, and the rest of science, have a future? Actually, we can be fairly certain that science is not on the verge of dissolving into a meaningless chaos, emulating the apparent destiny of the universe it studies. But it seems more and more obvious that we are standing on the threshold of a new scientific revolution. The inability of modern science to deal with the issues and questions raised at its frontiers is a situation which has arisen before, and the answers have always appeared in the form of radical new breakthroughs in scientific thought. Victor Clube of the Royal Observatory in Edinburgh, has argued persuasively that a number of astrophysical phenomena other than those discussed here, such as quasars, energetic galactic nuclei, and supermassive black holes, all currently under study, have proven so difficult for current theory to explain that only radical explanations in terms of a new physics will suffice. Others disagree. For example, the same Martin Rees who discussed the peculiar contingency of fundamental physical constants still believes that such super-energetic astrophysical processes as these can be adequately accounted for by "conventional" physics.

Virtually all modern scientists, however, agree that science is nowhere near accounting for all of reality. A famed nineteenth-century physicist advised his prospective graduate students to consider another field because, he believed, physics as a creative science was coming to an end — everything of significance had been explained, and there was nothing left to do but a little mopping up. The attitude he represented is quite definitely a thing of the past. Whether or not the mysteries presented by modern astrophysical cosmology are beyond the comprehension of modern science, the frontiers of science seem destined to remain as exciting as ever.

THE YOUNG PEOPLE'S MAGAZINE OF ASTRONOMY AND OUTER SPACE

Odyssey

what's up?
what's up?

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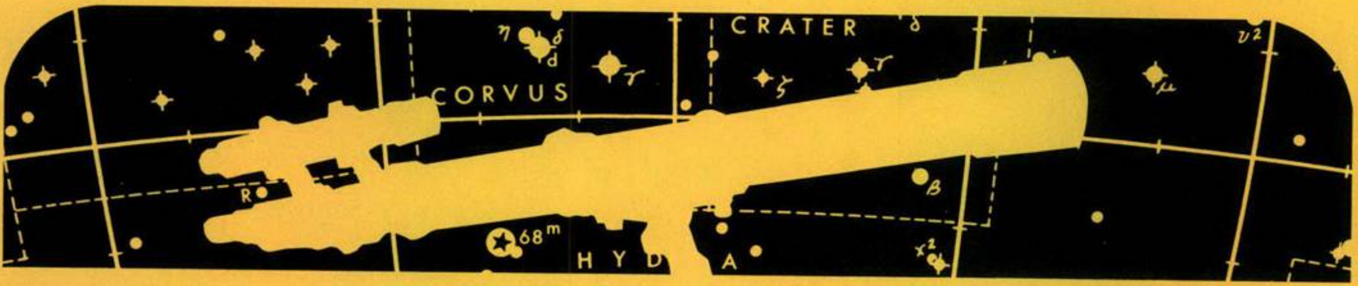


EQUIPMENT ATLAS

Read 'Um *and Don't Weep*

by

Ken Fulton

This article is aimed directly at those eager and nervous potential recruits who are about to get "ants in their pants" and jump in over their heads physically, financially, and psychologically when they purchase their first telescope. It concerns the ups and downs of purchasing a new telescope and their potential effect upon the individual. It is not so much about hardware as it is about the person, young or old, who works his tail off to buy that large, portable reflector loaded with all those expensive accessories only to find that when it arrives, the shipping charges were more than he had ever dreamed, he can't lift it alone without straining something, has no way to transport it, no place to use it, and no place to store it. So what happens? The telescope gathers dust. Spiders weave webs about the spider and admire themselves in the mirror. The owner broods about all that money spent on something he can't use. It aggravates him. The void in his bank account worries him. Eventually, sick at heart and thoroughly disgusted, he sells the scope for half the price he paid and promises never to waste any money on astronomy again. He has lost. Everyone has lost except the lucky stiff who buys the used telescope.

I would love to save someone. Perhaps the following article will do just that.

****

So you're about to take the plunge and buy a telescope. You've got the fever real bad. Sleep ignores you. Your daydreams alternate from 40 mm wide-angle to 4 mm high-power. Your wallet has the shakes. Every time you see a number, there's a shimmering "f" before it. Take care. Astronomy could drive you crazy!

But take heart — as long as you check the water *before* you dive and learn just how deep you can safely go, it will be worth every chill.

I've had the fever myself for 19 years. I began observing with an excellent, inexpensive 4-inch reflector and a universe that just wouldn't quit. Now, six telescopes and thousands of observing sessions later, I can say that I have experienced firsthand all the ups and downs astronomy has to offer — and lived to tell about it.

Believe me, the ups can take you as high as you want to go. The downs? That's another ball game. They can make a vegetable out of you. My right knee (the one I kneel on to sight through my telescope's finder) must be part cauliflower.

But don't worry. I'm okay. Though my sweet wife thinks I'm insane to drive miles out in the wilds to seek a dark sky, an acre of ground without a single confounded vapor light, and a double star that probably won't resolve, I believe that I'm very sane. So what if my focusing hand twitches uncontrollably whenever I hear the words "eyepiece," "drop," and "dirt" during the passing of a single day? And I try not to worry when the words "eclipse" and "clouds" cause me to do silly things, like trying to direct-dial Poland or threatening to trade in my best reflector on a leaky bass boat and three weedless lures. I'm not insane — *I'm just crazy about astronomy!*

****

1. **Never Bite Off More Than Your Wallet Can Chew.**

It isn't worth it. Buy a telescope you can easily afford. Bigger *is* better when it comes to gathering light, but not when it comes to observing with genuine peace of mind while you're up to your orthoscopics in debt. You can't really enjoy a telescope if you have to worry about the payments — or the vacuum it left in your bank account. If you're rich, this still applies: the telescopes involved are just larger, that's all.

2. **Don't Let Telescope Fever Worry You.**

Half the fun of owning telescopes is in the years spent wanting — and working up to — larger and larger telescopes of different makes and designs. And half the surprise of owning telescopes lies in realizing that after you have worked up to what I call the Hernia Stage (10 to 14-inch portable reflectors), you'll find yourself browsing the magazine ads and catalogs in search of a smaller, more portable instrument just like the one you sold six months ago. Half the agony of owning telescopes is in finding that the smaller scope you now want costs 20% more and will take six months to complete. And half the mystery of it all is that, still, in the back of your mind, you would give your eyeteeth to own that 1200 pound 16-inch that disassembles in two minutes into 63 parts and fits into the glove compartment of a VW.

3. **Do Some Hard, Realistic Thinking Before You Order.**

Study ads, articles, photos, and photo captions in ASTRONOMY. Order the dealers' catalogs and devour them, cover to cover, saving the fine print for dessert. Try to ignore your racing heart, the dealers' sales pitches, most adjectives, and figures like 1200x. Pay specific attention to the *real* telescope hardware description, accessories included in the base price, portability, assembled weight (which is quite different from shipping weight), guarantees, and packing and crating charges.

Write letters of inquiry to the dealers. As a courtesy, take the time to mention where you saw the ad. And especially talk turkey when it comes to delivery time (which can run to more than a year!), approximate cost of shipping, and the availability of optional accessories. Ask if there have been any changes made in the hardware since the last ad or catalog printing. Some time ago I purchased a $900 4-inch refractor advertised to include internal light baffles — but when I received the telescope, they weren't to be found. The dealer informed me that his company had not included them for years even though they were still mentioned in the most recent catalog description of the refractor. Again, read the fine print. The dealers reserve the right to make price and product changes any time they see fit. Sometimes those changes aren't improvements. So find out the nitty-gritty first, get it in writing, and keep it. That way, you are protected in case the company writes, "Oh, we don't include the mirrors anymore!"

4. **Prepare For That Precision Eye.**

While waiting for your new telescope, instead of nibbling your nails or unknitting your favorite sweater, get cracking. On clear nights, get outside with your red flashlight and the latest issue of ASTRONOMY and get to know the sky. If it's raining, brush up on the history of astronomy — or learn how to spell (or pronounce) Betelgeuse. Find out how to test a mirror or lens; how to align, balance and collimate; how to use a finder, setting circles, a star chart, a Barlow lens; how to care for your optics, etc. Read everything you can about astronomy, observing, and telescopes. Then, read it again.

5. **Know What You're Buying.**

Study Astro-Mart. There you'll find names and addresses of many people who share the same interests as you. Write them and ask for their opinions and suggestions. Include a stamped self-addressed envelope as a courtesy. Often, lasting and fruitful friendships germinate in just such a manner.

Study the catalog picture and description long and hard. Don't be in awe of the instrument when it arrives. Know it as best you can before you get it. Then, when you unpack it and your living room is literally full of out-of-state newspapers and used masking tape, you will instinctively know that the finder goes there and the star diagonal clamps on here and something should be over there. If something is missing, you'll know and try to find it. (Experience has taught me that it is probably buried under at least two feet of wrinkled classified ads, wrapped in the funny papers.) If, after searching each and every torn piece of paper, the missing object isn't found, you can inquire first with the shipping agent (especially in the case of concealed damage), then with the dealer. That way, you won't suddenly realize that just that morning, along with that unbelievable amount of packing paper, the garbage truck took your two finder brackets as well.

6. **Get To Know Your Telescope.**

Give yourself time to get acquainted with your new scope. And never, never be disappointed with your first view through it! It takes time to acquire the ability to appreciate the delicate wisps of starfog in something like the Lagoon Nebula. Just as you must *learn* to ride a bicycle or ski, you must learn to observe. Half the fun of observing is in realizing that you are getting better, that you can detect the greenish tint in that planetary nebula where before you had a hard time seeing a nebula at all. So don't let your first few sessions get you down simply because you can't see everything described in ASTRONOMY's Star Dome. You've got to work at it — this is what separates the sheep from the goats in astronomy.

7. **When You Show Your Telescope To Others, Be Gentle.**

Don't expect someone unfamiliar with observing and telescopes to walk right up to your little 4 mm lens and spot those tiny craterlets on Plato's floor. Often, they'll cover one eye with one hand, squint as if they're about to get a flu shot, approach the eyepiece like it's going to bite, grab the tube with their hand, kick the pedestal accidentally (for some reason, this *always* moves the telescope's line of sight to the only area in the entire universe void of stars), look at the glare of that ever-present vapor light in the lens, and just to be nice, say "That's nice." From then on, they suspect only that you have a very vivid imagination, and that you should be placed in a home.

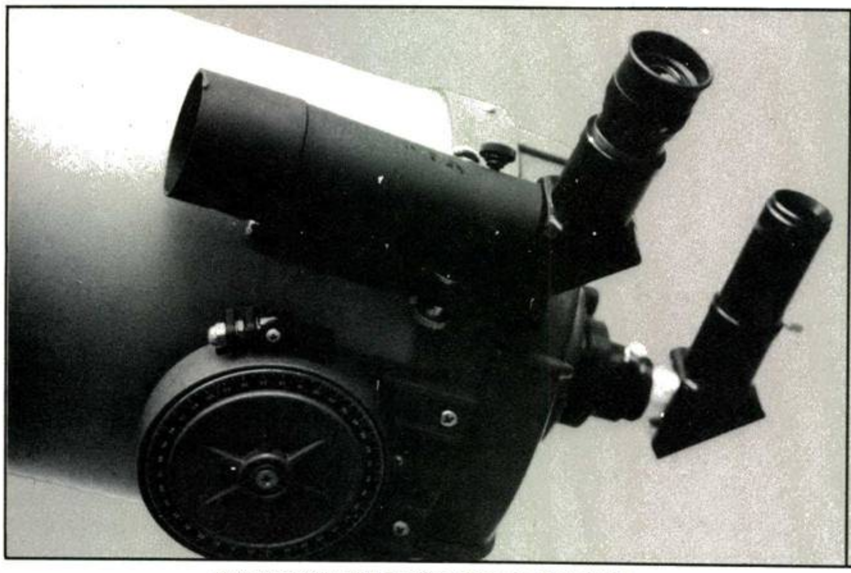
To prevent this, start them out with a wide-angle, low-power eyepiece. Buy the best you can easily afford, for you will use it often and come to love it. The eye relief is comfortable, the field bright and wide and obvious to the untrained eye. (Before you order, make sure it will fit the eyepiece tube of your scope.)

Be proud of your telescope and be eager to share it. You just might kindle an interest that will develop into a roaring devotion. The universe is something we all can share and still keep for ourselves.

8. **Don't Try Everything At Once.**

It's best to earn your stripes in observing before you move up to more specialized fields of work, like astrophotography. I wish that there was some unwritten law declaring that no person could even put a camera on his or her scope until he or she has logged at least 500 hours of genuine observing. There is so much to see — and so much to learn about how to see. It's very easy, for instance, after you get deeply involved in astrophotography, to slide into the habit of using eyepieces merely to locate and help track an object instead of to appreciate its beauty. This is sad. True, photographs are fantastic — and an integral part of astronomy — but they should *never* take precedence over those pictures that develop so softly, so well, so magnificently on the optic nerve of your eye. Of course, those pictures are never published, never impress friends or win awards, but they are always with you. They never gather dust or fade. And there's always that special pleasure in knowing that, when you look upon that distant light, it has traveled all those light-years — such an incredible journey — for you. Whenever I contemplate that, I swear it brings tears to my eyes.

Yes, I love the universe. Yes, I think it loves me.



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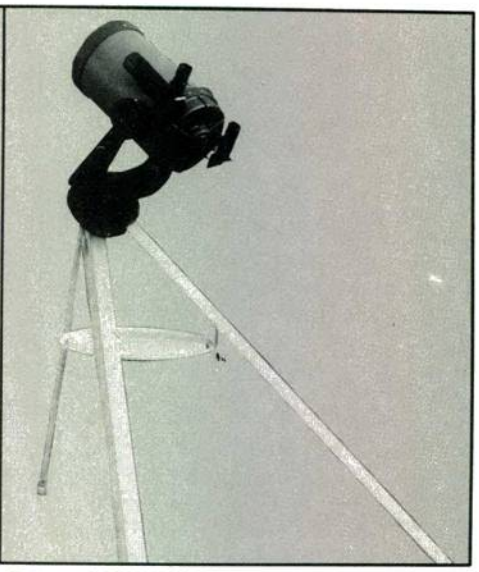

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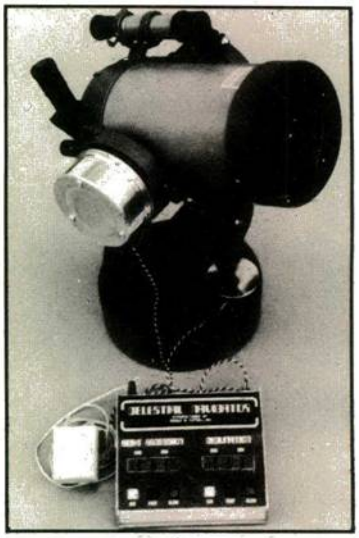

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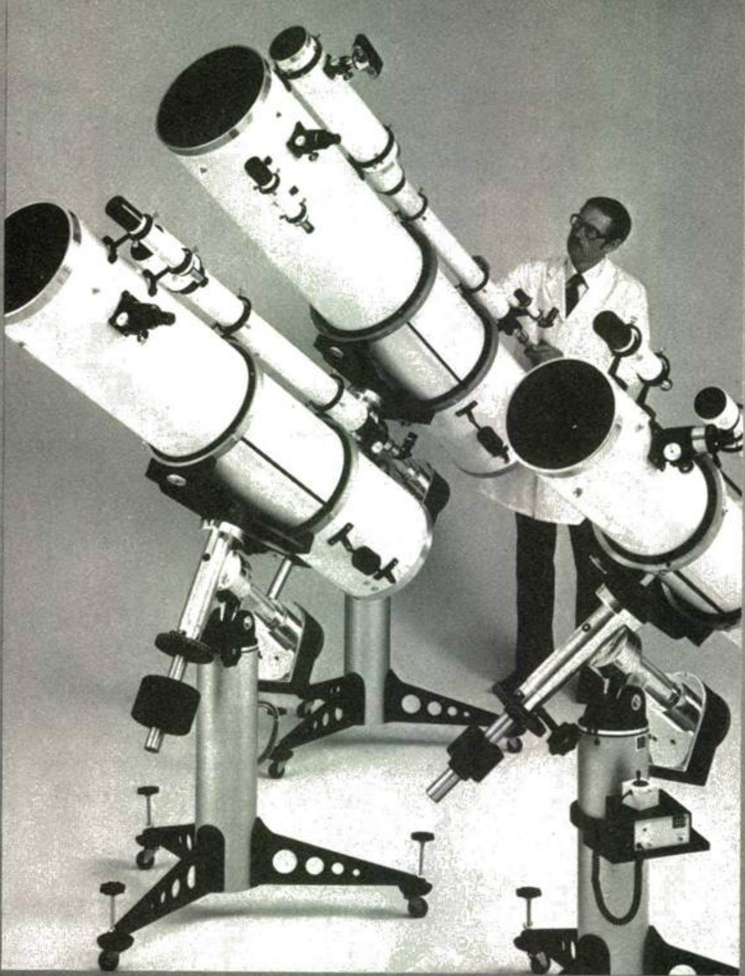

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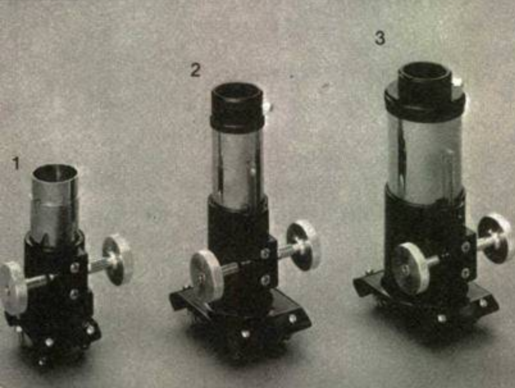

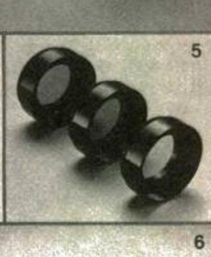

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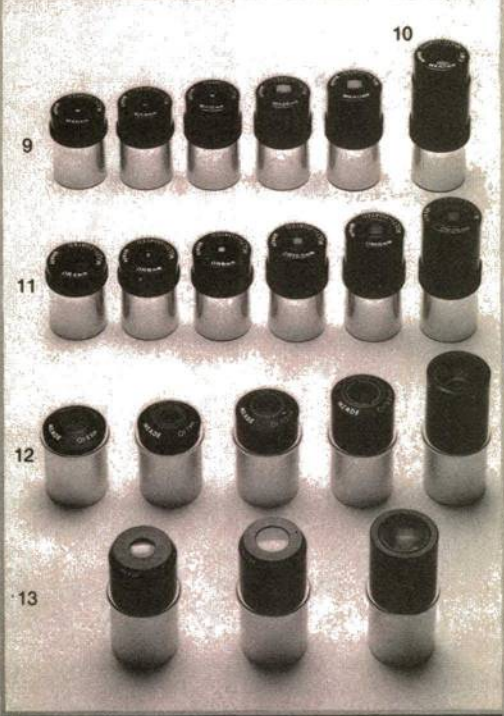

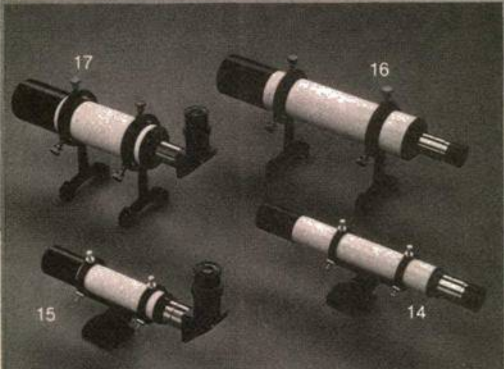

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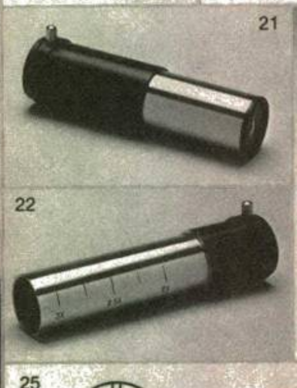

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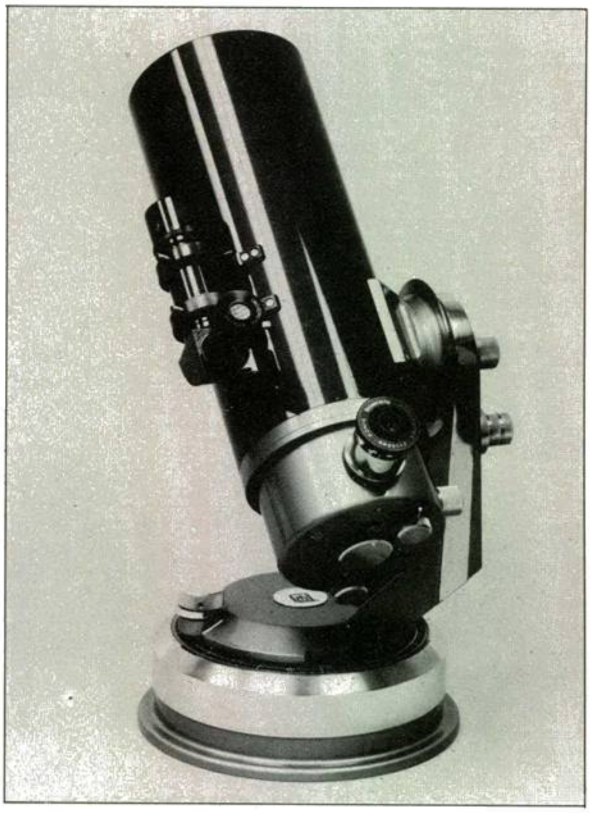

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> "I had the opportunity to view through a Quantum Four. It is indeed a superb telescope and after it had settled down, we split the double-double easily with hard Airy disks and one faint spurious ring. The only instrument there which could compare with it on this object was my 4¼-inch Schiefspiegler, which gave similar images. However, one must admit that the Quantum was more compact and had no air currents like the open tube TCT instrument."

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Stellar Metropolises:

The Globular Clusters

by

Michael Witkowski

A casual glance upward on a clear, moonless night will reveal myriads of dim background stars contrasted with certain conspicuous, close, bright groupings. Your initial reaction might be to segregate various outstanding configurations whose members seem to be related. Since antiquity, man has associated the stars in the same region of the sky with one another. Thus constellations were invented, corresponding myths and legends arose and passed through the generations, and even today astronomers recognize most of the same star patterns that their ancient predecessors did. But in spite of several millenia of rich lore, the major stars in the constellations are not truly associated; the figures they seem to depict are solely the result of their chance distribution throughout our Galaxy, and their relationship does not extend beyond their use as reference points for Earthbased observers.

Many genuine groupings or clusters of stars do exist, however, but since they are much farther from us than most of the bright stars, they aren't as conspicuous to the naked eye as are "artificial" groupings like constellations. True clusters come in two distinct varieties: (1) *open*, or galactic clusters, which contain several dozen to several hundred members each; and (2) *globular*, sometimes called global, clusters which contain several hundred thousand to possibly a million members each.

In this article we're going to show how you can survey the globular clusters visible from North America —even if all you have is a modest-sized (2 to 8-inch aperture) telescope.

Globular clusters are dense, roughly spherical aggregations of stars which form a halo around the center of our Galaxy. Approximately 100 have been identified and cataloged, and perhaps 100 more exist, hidden from us by the thick, dusty central concentration of the Milky Way. Most lie between 10,000 and 100,000 light-years from us, although a few are thought to be as remote as 200,000 light-years. Due to their immense distances, scarcely half a dozen globulars can be seen (barely) with the naked eye. All except Omega (ω) Centauri and 47 Tucanae, both southern hemisphere objects and by far the two finest examples, appear as dim patches of glowing haze.

A pair of binoculars will reveal larger and brighter patches, while a small telescope will show central condensations accompanied by outward extensions which resolve to varying degrees into stars depending on the individual cluster and the observing conditions. Large telescopes and long photographic exposures of globular clusters show a brilliant, solid nucleus accompanied toward the margins by countless stars.

So unmistakable is the appearance of a globular cluster that its identification as such will never be in doubt. In fact, differences from one cluster to another of comparable size and brightness are generally distinguishable only to moderately-seasoned observers. An unimaginative viewer might even dismiss the entire group as a dull class of many very similar objects.

Admittedly, globular clusters don't display the diversity that other deep-sky objects do. The planetary nebulae, with the Ring in Lyra and the Dumbbell in Vulpecula leading the parade, and the diffuse nebulae, of which M-42 in the sword of Orion is probably the foremost member, are all quite individual and distinctive. The great galaxies and open clusters also come in many sizes and shapes.

But variety isn't everything. The bright planetary and diffuse nebulae are few and far between, while the galaxies, though very numerous, are extremely difficult to observe and, with the exception of the Andromeda Nebula and the Magellanic Clouds, require optimum conditions. The open clusters, also quite numerous, are seen most easily in winter so observing them is often hindered by cold weather, especially in the higher northern latitudes.

Globular clusters, on the other hand, are among the easiest objects to observe with modest equipment. Twenty-nine are bright enough to carry M designations, numbers assigned by Charles Messier (an eighteenth century comet hunter) and his colleagues to 100 or so of the most prominent deep-sky objects visible from the northern latitudes. Since the total number of known globulars is only about 100, you can easily locate a significant percentage of them in a

Left: Known as the Great Cluster in Hercules, M-13 is probably the most familiar of all the globulars. It can be seen with the naked eye on a clear night, and is a grand sight through a telescope. Leo Henzl photo. Above: Visible from the southern hemisphere and to low-latitude northern observers, Omega Centauri is a glorious sight. Omega, like 47 Tucanae, was at first thought to be a star and so they were both given "stellar" designations. It looks clearly oval in the telescope and on long-exposure photos. Photo by Leo Henzl.

short time. In addition, almost all are warm weather objects so you aren't combating the elements during a globular hunt.

Spring

With the beginning of spring, a small yet spectacular group of globular clusters appears. M-3 in Canes Venatici, M-5 in Serpens, and M-13 and M-92 in Hercules are the prime members.

M-3 is the first noteworthy spring arrival. Rising at sunset in mid-March, this splendid stellar family is well situated for observing by 9:00 p.m. in early April. Lying on a line almost halfway between Cor Caroli (Alpha Canum Venaticorum) and the bright star Arcturus, it is quite easily found. A good three or four-inch telescope at 100 power should start to resolve some individual stars at the edges, while a six or eight-inch reveals an almost countless number of light points for a truly breathtaking sight.

Close to M-3 in the constellation Coma Berenices are two much less spectacular globulars, M-53 and NGC-5053. (NGC denotes **New General Catalogue**, an 1888 listing of approximately 8,000 deep-sky objects.) M-53 is easily visible through a small telescope, although no resolution can be expected, and while NGC-5053 may present somewhat of a challenge, finding it will give you a very definite sense of satisfaction. The magnitudes of these two clusters are 6.9 and 10.5 respectively. Obviously they are not the showpieces that M-3 at magnitude 4.5 is, but nevertheless they are worth trying to find. Both lie about 15° west of Arcturus.

M-5, M-13, and M-92 rise a few hours later than M-3 and by May are readily observable soon after twilight.

M-5, 11 degrees north of the relatively isolated star Beta (β) Librae, would ordinarily be easy to find, but it is nestled among a group of undifferentiated fifth and sixth magnitude stars, so low powers should be used to locate it. Once found, this large and handsome aggregation of suns will captivate its viewer, and while its individual stars are not as resolvable as, for example, M-3's, M-5 is among the most spectacular globular clusters in the entire sky. In fact, this cluster, listed at magnitude 3.6, is tied with M-22 in Sagittarius for third place in brightness. Yet it never gets the recognition it deserves. Much of that goes to its northerly neighbor, M-13, the Great Hercules Cluster.

M-13 is the most talked about, most observed, and most photographed globular cluster in the heavens. Why? Omega Centauri and 47 Tucanae are both much larger and brighter, while M-2, M-3, M-4, M-5, M-10, M-15, M-22, M-55, and M-92 are all similar to M-13 in size and brightness. Obviously the nickname, "The Great Hercules Cluster," implies something special and attracts immediate attention. In fact, no other globular cluster has a nickname.

But other reasons help bring M-13 recognition. Its easy-to-remember location, two-thirds of the way from Zeta (ζ) to Eta (η) Herculis, which are almost exactly north-south, quite often makes it a first for beginners. Also, M-13, being at a high northerly declination, is visible at a reasonable hour of the night most of the year. Of its rivals, only M-92 is more northerly.

Above: M-19, in Ophiuchus, is one of the most elongated of all globular clusters, and lies about 1 kiloparsec from the galactic center. Ben Mayer photo on hydrogenated 200 ASA film in a cold camera using a C-14. Opposite page A: 47 Tucanae is one of the closest of the globular clusters, though its great southern declination prevents it being seen from most northern latitudes. Harvard Observatory photograph. B: M-3 was discovered by Messier in 1764, and astronomers estimate it contains about a quarter of a million times our Sun's mass in stars. Lick Observatory photo. C: M-5 in Serpens, is about 25,000 light-years away, and is thought to be one of the oldest clusters, aged 15 to 20 billion years. D: M-56 is a small, round, and compact cluster about 40,000 light-years away. C. Bowland photo through an 8" Schmidt-Cassegrain, using 103a-F.E: The only winter globular to bear an "M" number, M-79 is in Lepus, to the south of Orion. Photo by Thomas Dessert, taken through his 10" f/6 telescope onto 103a-F. F: M-15, in Pegasus, is clearly seen with just the slightest optical aid, and is truly magnificent through a telescope. Photo by M. Germano, on 103a-F through an 8" Schmidt-Cassegrain.

By contrast, M-4, M-22, and M-55 are so far south that they are only seen for a few months from the northern latitudes. Finally, M-13 is visible to the naked eye more often than its equals which lie too near the horizon and are frequently lost through a thick blanket of atmosphere. Quite clearly, M-13 has much in its favor from an observer's viewpoint.

M-13 is also spectacular intrinsically, as any optical aid will demonstrate. Resolution of individual stars begins at 100 power through a four-inch reflector, while a six-inch instrument will show hundreds of stars seemingly reaching out from a brilliant center beckoning your undivided attention. Certainly, no evening of observing is complete without a long look at this marvelous celestial showpiece.

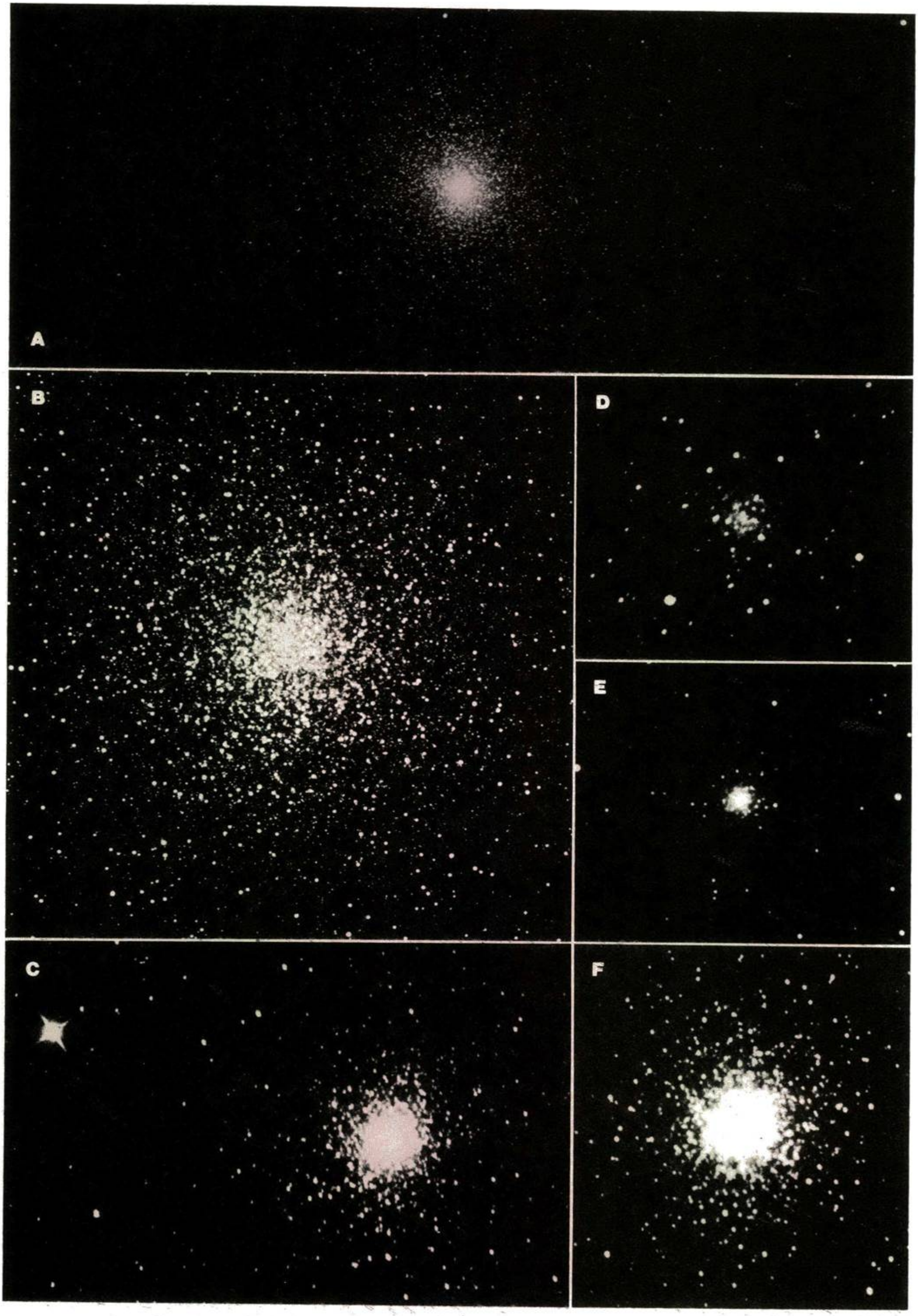
M-92, which lies about 10° northeast of M-13, is a bit smaller, dimmer, and harder to resolve than its impressive neighbor. Also, it is not found as easily, having no obvious and instant reference points. But in its own right, M-92 is a magnificent sight through almost any telescope. To locate it, look one degree east of Pi (π) Herculis, the northeastern star in the Hercules Keystone, and eight degrees north. If the seeing is good and the sky is dark, this object will nearly match any other globular in the sky except Omega Centauri and 47 Tucanae.

Summer

Summer skies abound with globular clusters. Of the 29 Messiers, 16 reside in the contiguous constellations of Scorpius, Ophiuchus, and Sagittarius.

M-4 and M-80 in Scorpius contrast interestingly. M-4, 2° due west of Antares and one of the easiest globulars to locate, is spread out and consequently quite resolvable at high power, while M-80 is very compact and not easily resolved. M-80 appears to be the more brilliant, but M-4 is listed as brighter (see table). This apparent discrepancy arises because magnitudes for extended objects (i.e., globular clusters, galaxies, open clusters, etc.) indicate the total light of the object. A large, bright object may actually appear fainter than a small, dim source that's compact. On the other hand, stellar magnitudes measure only the light from a single point source, and no such ambiguities appear.

Sweeping east from Antares 8° and crossing into Ophiuchus, you'll find M-19. This is only an average globular cluster with respect to magnitude, resolvability, and size, but it is a very handy reference object for several others of its kind. Using a wide field eyepiece, sweep north 4° and try to catch the two dim clusters NGC-6284 and NGC-6287. Go east 7° for the equally dim clusters NGC-6293 and NGC-6355, or south 5° for M-62, a virtual twin to M-19.


A
B
D
E
C
F

Also in Ophiuchus are the fairly bright clusters, M-9, M-10, M-12, and M-14 and the dimmest Messier globular, M-107. Unfortunately, there are no direct pathways to or from any of these almost neglected objects, so naturally the Scorpius and Sagittarius clusters are better known. However, don't overlook this pleasant group. Any good star chart such as the **Seasonal Star Charts**, **Norton's**, or the **Atlas Coeli** will guide the way.

Turning toward Sagittarius, in the direction of which lies the center of the Galaxy, you'll encounter a rich assortment of deep-sky treasures. Two of the gems are the globular clusters M-22 and M-55. M-22 is located a short 3° northeast of third magnitude Lambda (λ) Sagittarii, while M-55 stands starkly isolated in a relatively starless field. From a favorable location, both M-22 and M-55 are spectacular, easily rivaling M-13. M-22 is interesting in a finderscope or binoculars since it rests symmetrically between two small groups of dim stars. M-55, by contrast, completely dominates its little celestial domain.

The additional Messier globulars in Sagittarius are M-28, M-54, M-69, M-70, and M-75. Their magnitudes range from 6.8 to 8.6, well within the limit of most modest telescopes.

M-56 and M-71 are two fairly easy summertime globulars which are overshadowed by well-known neighbors. M-56 lies halfway between Albireo (β Cygni) and Gamma (γ) Lyrae, and is quickly located. But residing in the small, yet rich constellation Lyra, this globular is often forgotten. Among its neighbors are the famous Ring Nebula, the bright star Vega, and the "double double" Epsilon (ε) Lyrae. M-71, one of the least compact of all globulars and sometimes classified as an open cluster, lies between the two easternmost stars in the arrow of Sagitta, yet despite its ease of location, it takes a back seat to the well-known Dumbbell Nebula only 5° to the north.

Globular Clusters

NGC	Other	Constel.	R.A. (1975)		Dec.		Size	Mag.
104	47 Tuc	Tuc	0^h	23^m	-72°	13′	23.0	3.0
288		Scl	0	51	-26	44	10.0	7.2
362		Tuc	1	02	-70	59	5.3	6.0
1851		Col	5	13	-40	03	5.3	6.0
1904	M-79	Lep	5	23	-24	33	3.2	8.1
2419		Lyn	7	37	38	57	2.0	11.5
2808		Car	9	11	-64	45	6.3	5.7
4590	M-68	Hya	12	38	-26	37	2.9	7.6
5024	M-53	Com	13	12	18	18	3.3	6.9
5053		Com	13	15	17	48	3.5	10.5
5139	ω Cen	Cen	13	25	-47	21	23.0	3.0
5272	M-3	CVn	13	41	28	30	9.8	4.5
5897		Lib	15	16	-20	55	7.3	9.5
5904	M-5	Ser	15	17	2	11	13.0	3.6
6093	M-80	Sco	16	16	-22	56	3.3	6.8
6121	M-4	Sco	16	22	-26	27	14.0	5.2
6171	M-107	Oph	16	31	-12	59	2.2	8.9
6205	M-13	Her	16	41	36	30	10.0	4.0
6218	M-12	Oph	16	46	-1	55	9.3	6.0
6229		Her	16	46	47	34	1.2	9.7
6254	M-10	Oph	16	56	-4	04	8.2	5.4
6266	M-62	Oph	17	00	-30	05	4.3	7.0
6273	M-19	Oph	17	01	-26	13	4.3	6.8
6284		Oph	17	03	-24	43	1.5	10.0
6287		Oph	17	04	-22	40	1.7	10.4
6293		Oph	17	09	-26	32	1.9	8.8
6333	M-9	Oph	17	18	-18	30	2.4	7.4
6341	M-92	Her	17	16	43	10	8.3	5.1
6355		Oph	17	23	-26	19	1.5	10.0
6397		Ara	17	39	-53	40	19.0	4.7
6402	M-14	Oph	17	36	-3	16	3.0	7.4
6626	M-28	Sgr	18	23	-24	53	4.7	6.8
6637	M-69	Sgr	18	30	-32	22	2.8	7.5
6638		Sgr	18	29	-25	31	1.4	9.2
6656	M-22	Sgr	18	35	-23	57	17.0	3.6
6681	M-70	Sgr	18	42	-32	20	2.5	7.5
6715	M-54	Sgr	18	54	-30	30	2.1	7.1
6779	M-56	Lyr	19	16	30	08	1.8	8.8
6809	M-55	Sgr	19	39	-31	00	10.0	4.4
6838	M-71	Sge	19	53	18	43	4.0	8.0
6864	M-75	Sgr	20	05	-22	00	1.9	8.6
6981	M-72	Aqr	20	52	-12	38	2.0	8.6
7078	M-15	Peg	21	29	12	04	7.4	5.2
7089	M-2	Aqr	21	32	-0	56	8.2	5.0
7099	M-30	Cap	21	39	-23	18	5.7	6.4

Listed in this table are the 45 globular clusters which are the easiest to locate. The column heads are self-explanatory, but note the coordinates are for 1975, and the size is in minutes of arc.

Autumn and Winter

Moving to autumn skies, the sampling of globular clusters thins out considerably since you are now looking away from the center of the Galaxy.

M-30 in Capricornus at magnitude 6.4 and M-72 in Aquarius at magnitude 8.6 are not particularly spectacular or easy to locate. However, M-2 in Aquarius and M-15 in Pegasus are. M-2 lies 4° north of Beta (β) Aquarii, and M-15 lies 13° north of M-2. Both are of magnitude 5.1 and approximately the same size, though M-15 appears easier to resolve into individual stars. You'll do best using 150 power or higher.

Another noteworthy autumn globular is NGC-288 in Sculptor. This is not a very bright object since it spreads out a bit, but finding it shouldn't be difficult. Look 9° south and 2° east of Beta (β) Ceti, the only bright star in this region of the sky. Although not particularly well-situated for northern observers, NGC-288 is a good test object for a small instrument when conditions permit.

The lone winter globular cluster bearing an M number is M-79 in Lepus, south of Orion. At magnitude 8.1, it is bright enough to be seen easily in a three-inch telescope, although you won't resolve it without at least an eight-inch.

The only other winter globular is NGC-2419 in the faint, inconspicuous constellation Lynx. The most distant of all known globulars belonging to our Galaxy, it's listed at magnitude 11.5. Realistically, you'll find it almost beyond the ability of most small telescopes, but it is worth a hard search, for if you succeed, you'll be looking at an object approximately 200,000 light-years away: at, or perhaps beyond, the very edge of the Milky Way.

After M-79 and NGC-2419 are high in the sky, the springtime constellations begin to peek over the eastern horizon, indicating that once again the year's parade of globular clusters is about to commence.

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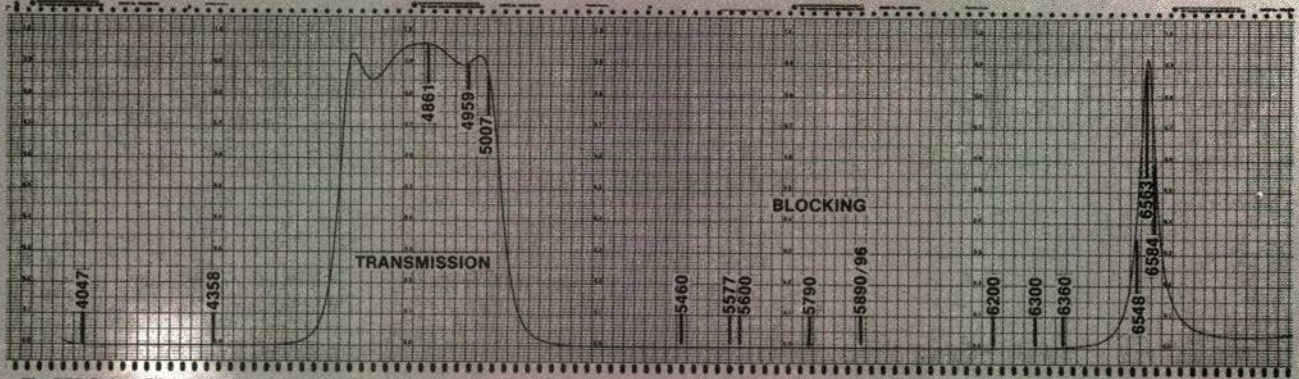

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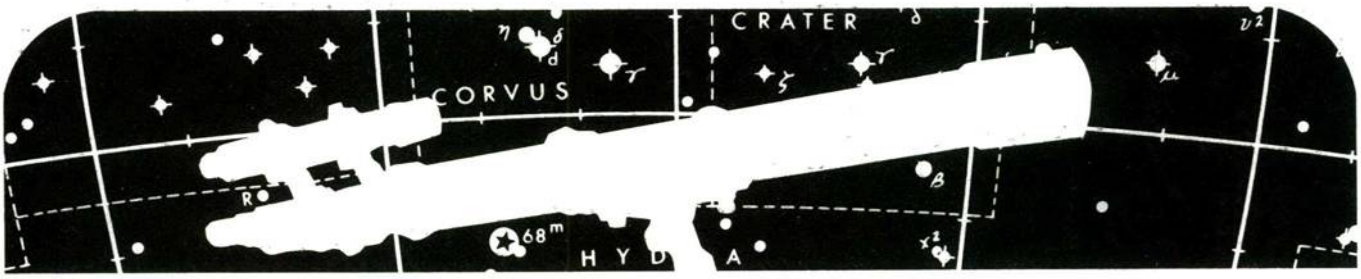


EQUIPMENT ATLAS

Celestial Software, Part 6:

Brightness and Magnitude

"Look how bright the stars are tonight." But how bright is bright? That's a question astronomy has answered in a very precise way, by means of the concept of *magnitude*. The question may seem simple enough, but as it turns out, the answer is more complex than you might think, for there are a number of different magnitude scales. Each answers the question "How bright is bright?" in a slightly different way.

The Concept of Magnitude

The idea of magnitude as a measure of brightness is a very old one. In fact it goes all the way back to Hipparchus of Nicaea, the greatest of the Greek astronomers, who died about 120 B.C. At his observatory on the beautiful Aegean island of Rhodes, Hipparchus organized the first system of stellar magnitudes. He divided all the stars into six classes of brightness. The brightest stars in the sky were said to be of the "first magnitude," and Hipparchus called the very faintest stars that could be seen with the naked eye "sixth magnitude." The other stars were grouped into second, third, fourth, and fifth magnitude groups in order of decreasing apparent brilliance. Of course the fainter the class, the more stars were found in it, ranging from twenty stars in Hipparchus' first magnitude class to several thousand of the sixth magnitude.

Magnitude Difference	Difference in Brightness
1	2.5
2	6.3
3	15.8
4	39.8
5	100
6	251
7	631
8	1585
9	3981
10	10,000

This table shows the actual difference in brightness (apparent luminosity) corresponding to a particular magnitude difference. Thus, if one star is magnitude 3.4 and another is 7.4, their magnitude difference is 4, and the first is about 40 times as bright as the second.

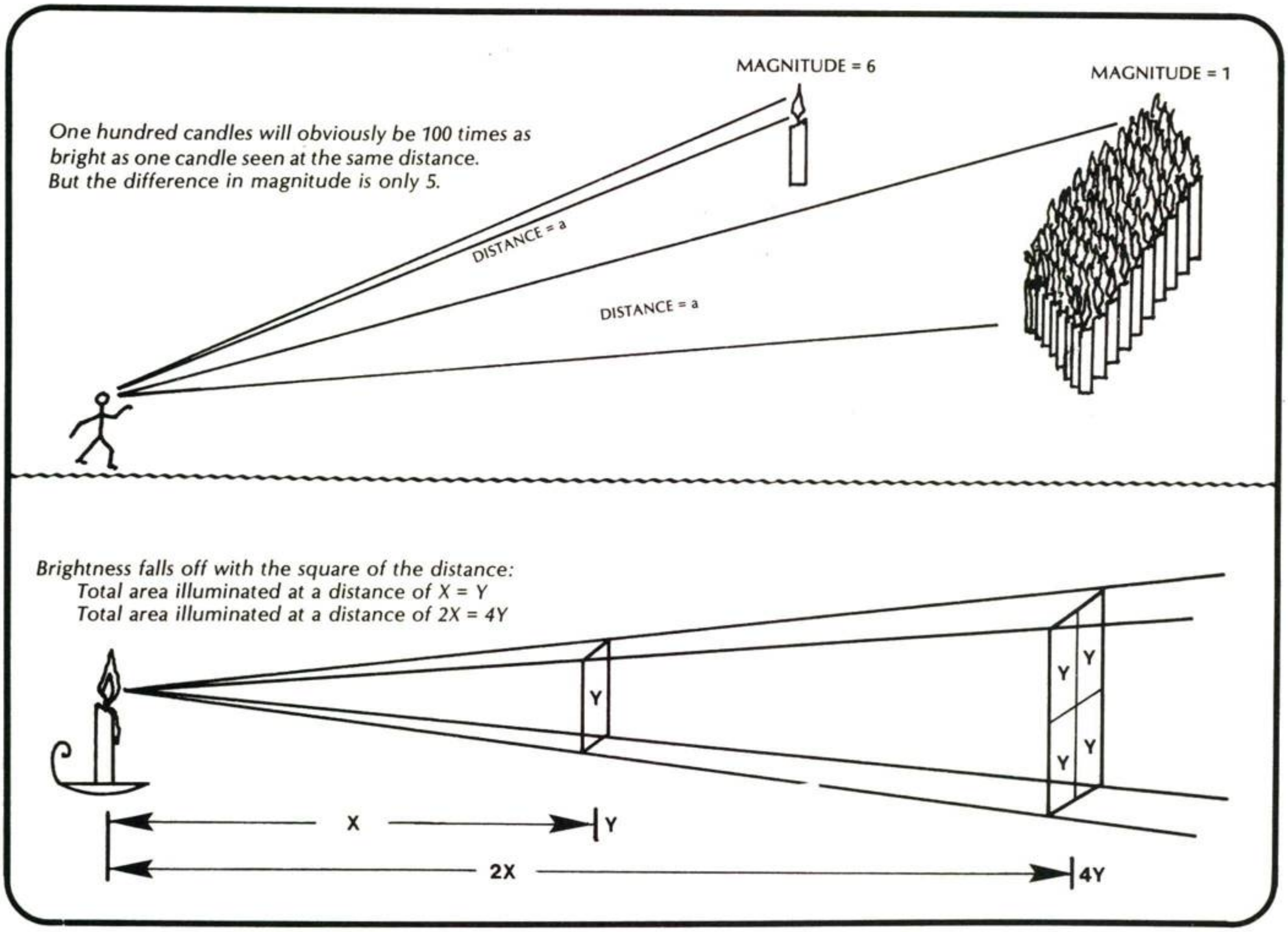
The system made sense and was correlated very well to the actual apparent brightnesses of the stars, so it has been retained, though considerably refined and extended, to the present day.

Hipparchus' system was basically qualitative — stars seemed subjectively to fall into six classes or levels of brightness. The next step in the evolution of the modern magnitude scale was its precise definition in the quantitative language of mathematics. This was accomplished over a hundred years ago by the English astronomer Norman Pogson. In 1850 Pogson noted that an average first magnitude star was just about a hundred times as bright as a sixth magnitude star. He proposed, therefore, that the magnitude scale be made mathematically exact by specifying that a difference of five magnitudes be defined as being equal to a factor of 100 in brightness.

Since Hipparchus had defined the brightest stars as being of the first magnitude, with the magnitude number increasing as brightness decreased, the numerical scale works in reverse. A numerically large magnitude denotes a dim star. If a sixth magnitude star were as bright as a single candle at a distance of, say, fifty feet, then according to Pogson's rule, a first magnitude star's brightness would be that of one hundred candles at the same distance. But the numerical difference is only five magnitudes. This is because the magnitude scale progression is geometric rather than arithmetic — changing by multiplication rather than addition. (An example of an arithmetic progression is 1, 2, 3, 4, 5 .., while a geometric progression is one like 1, 2, 4, 8, 16, 32....)

Finding the multiplying factor for the magnitude scale is easy: following Pogson, we say that five magnitudes is equivalent to a hundredfold difference in brightness. So the difference between any two magnitudes — D — will be the fifth root of 100. Since D × D × D × D × D = 100, or $D^5 = 100$, solving for D gives us 2.512. Therefore, a fourth magnitude star is about two and a half times as bright as a fifth magnitude star, which is in turn two and a half times as bright as a sixth magnitude star, and so on.

Having such a mathematical scale enables us to extend the magnitude system below sixth for objects too faint to be seen and above first for objects brighter than the first magnitude



One hundred candles will obviously be 100 times as bright as one candle seen at the same distance. But the difference in magnitude is only 5.

Brightness falls off with the square of the distance:
Total area illuminated at a distance of X = Y
Total area illuminated at a distance of 2X = 4Y

stars. Accordingly, a star 2.512 times brighter than first magnitude will be of magnitude 0; ones brighter still will have negative magnitude numbers. On this basis, the magnitude of the brightest star in the sky, Sirius, is -1.58, Venus at its brightest reaches about -4.3, the full Moon shines at about -12.2, and the Sun blazes forth at -26.7. In the other direction, we find the faintest planet (Pluto) at about 14th magnitude, and the faintest objects which can be photographed with the largest telescope on Earth are about magnitude 23 — over *100 billion billion* times fainter than the Sun. (23 + 27 = 50 magnitudes; 2.512^{50} = 100,000,000,000,000,000,000.)

Apparent and Absolute Magnitudes

At this point we have to make a distinction between *apparent* magnitude and *absolute* magnitude, because this is crucially important to astronomers. Two objects may appear to be equally bright, thus having the same apparent magnitude, but if one is much farther away, we know that in reality it must be brighter than the other.

To be exact, if it is twice as far away, it must be four times as bright, and if three times as far away, nine times as bright intrinsically. This happens because the intensity of light as it travels out from an object gets dimmer as the inverse square of the distance. Twice as far away, for example, the same number of photons will be spread out over an area four times as large. So for a real comparison of the brightness of two objects, we would have to observe them from an equal distance.

Of course the stars all lie at vastly differing distances from us, so their apparent magnitudes have nothing to do with how bright they actually are. A particular star may be bright only because it is close to us, while another may appear faint only because of its great distance.

For this reason, astronomers often refer to what is called an object's absolute magnitude. This is the magnitude the object would have if it were at a fixed distance from us. This standard distance has been set by astronomers at 10 parsecs (about 32.6 light-years).

On this scale, the Sun becomes a fifth magnitude star. But there are stars whose absolute magnitude is much fainter than that, stars such as Proxima Centauri, the tiny red dwarf in the Alpha Centauri system, whose absolute magnitude is 15½. In the other direction, the most luminous stars, such as S Doradus, blaze with an absolute magnitude of -8 or even -9. So the Sun, in this respect as in many others, is quite an average star.

Brightness and Luminosity

So far we have been talking in terms of "brightness." But what does brightness mean? What do we mean when we say that one star is twice as bright as another, or that a difference of one magnitude is a factor of 2.512 in brightness?

Electromagnetic radiation, from radio waves through visible light to X-rays and gamma-rays, carries energy. The exact amount carried by each photon can be calculated, and is dependent on its wavelength. The shorter the wavelength, the more energetic the photon; photons of long wavelengths carry very little energy. Brightness, then, is simply a measure of the amount of electromagnetic energy we receive from an object. More energy means it is "brighter"; less energy, and it seems "fainter."

But astronomers do not speak in terms of "brightness," with its overtones of subjective human perception. Rather, the term *luminosity* is used instead, defined as the total amount of electromagnetic energy coming from an object in a period of one second. The luminosities of stars are usually measured in units defined by that of the Sun, and range from a

Theoretical Limiting Magnitudes for Telescope Apertures

Aperture in Inches	Magnitude Limit
3	11.2
4	11.8
4¼	11.9
6	12.7
8	13.3
10	13.8
12	14.2
14	14.5
16	14.8
20	15.3
36	16.6
84	18.4
100	18.8
200	20.3

The limiting magnitudes given in this table are based on an approximate calculation. Photographically, stars much dimmer than the limiting magnitude can be recorded, and with excellent seeing, magnitudes fainter than those listed here can sometimes be seen. The limiting photographic magnitude for the 200-inch telescope is estimated to be about 23.

high of one million suns down to one millionth of a sun.

Apparent luminosity, then, is the amount of electromagnetic energy actually received by the observer from an object, and will obviously depend on its distance from us as well as on its intrinsic, or absolute, luminosity.

Bolometric Magnitude

Useful as they are, absolute visual magnitudes may not give us a true indication of the relative luminosity of two objects. As we saw above, the *visual* magnitude of an object is just a measure of its brightness, or luminosity, over the visual range of wavelengths. What about all those other wavelengths, shorter and longer than those of visible light? Obviously they will contribute to the total luminosity. So if a particular star, say, emits a great deal of its energy in the invisible, far-ultraviolet part of the spectrum, it may look no brighter than another star which concentrates its output in the visible spectrum. But its true luminosity over the entire spectrum will be much greater. Is there any way to measure this?

Yes, there is: when astronomers wish to deal with the total energy output of an object rather than just its output in the visible range, they refer to its *bolometric* magnitude instead of its visual magnitude. Just as in the case of visual magnitude, the bolometric magnitude of an object may be an apparent bolometric magnitude, or if corrected to a distance of 10 parsecs, an absolute bolometric magnitude.

The bolometric magnitude is useful because it is a measure of the actual total luminosity of an object over *all* wavelengths — a measure of the total energy received (in the case of apparent bolometric magnitude) or actually emitted (absolute bolometric magnitude).

Of course there are many things which can reduce the total radiation we receive from celestial objects. The atmosphere blocks out substantial portions of the electromagnetic spectrum, and even when we observe from above the atmosphere, there are other effects, such as absorption of radiation by interstellar gas and dust. So it isn't possible to measure the bolometric magnitudes of celestial objects directly. Fortunately, though, we understand enough of the physics of most cosmic processes to be able to infer from what we *can* observe, what the total luminosity of an object actually is, and thus derive its bolometric magnitude. There have been surprises, though — such as the case of stars which have been discovered to emit strongly in the X-ray part of the spectrum — and others may be in store for us as measurements from satellite observatories increase and become more exact.

In many cases, the bolometric magnitude (either apparent or absolute) of an object will be almost the same as the (apparent or absolute) visual magnitude, provided most of the object's radiation falls in the visual part of the spectrum. But when a substantial amount of energy comes at other wavelengths, the bolometric magnitude may be quite different. The exact amount of the difference is called the *bolometric correction*. In the case of a star like the Sun, the bolometric correction is nearly zero, but for very hot stars emitting a lot of energy in the ultraviolet, it may be as great as four magnitudes or more. Since the bolometric magnitude is always brighter than the visual, the bolometric correction represents a shift of the visual magnitude in the negative (brighter) direction, and hence is always a negative number.

Other Magnitude Scales

The visual and bolometric magnitude scales aren't the only ones astronomers have defined. The visual scale measures luminosity over the visible part of the spectrum, while the bolometric spans the whole spectrum. But there are several other scales which have been found useful in modern astronomy, and which make use of some other specific portions of the spectrum.

One of the most obvious is *photographic* magnitude. This is simply the magnitude of a star as measured directly on a photographic plate. But the spectral responsiveness of a photographic plate is not necessarily the same as that of the human eye. The early plates used in astronomy recorded light mostly from about 4000 to 5000 Angstroms, in the blue-violet part of the spectrum. For this reason, the photographic magnitude is usually quite different from the visual magnitude. When the measurement of a star's magnitude over this range of blue wavelengths is made directly by a photometer, it is called the star's **B** magnitude.

Measurement of stellar images on photographic plates is a particularly rapid and easy way to determine magnitudes, so for a quick survey of many stars, this is the method used. In order to get a value for the visual magnitude of a star, special plates combined with filters can be used so that the spectral responsiveness of the plate is about the same as that of the eye, spanning the range from 5000 to 6000 A. Magnitudes determined in this way are called *photovisual* magnitudes, and are virtually identical to the visual magnitudes. Again, a magnitude in this region of the spectrum measured by the exact method of photoelectric photometry is abbreviated as a star's **V** magnitude.

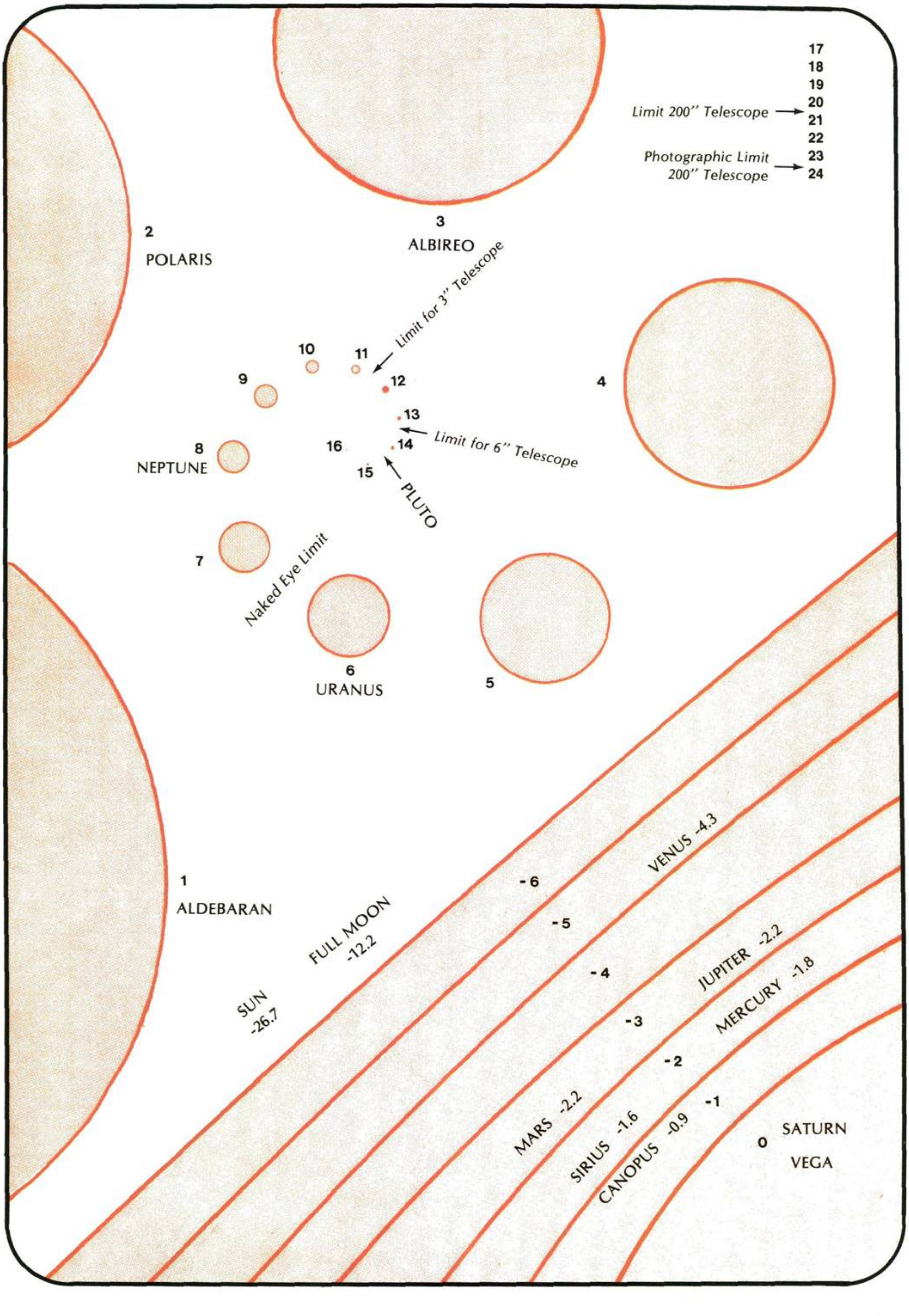
A third scale, based on a star's measured brightness in the near-ultraviolet (around 3600 A), is very important to astronomers. A magnitude measured by a photoelectric photometer on this scale is referred to as the star's **U** magnitude.

The last three magnitude scales taken together comprise what is called the **UBV** system. The details of this system are too complex to deal with here, but the relative values of stars' **U**, **B**, and **V** magnitudes have proven highly important to astronomers in working out the details of stellar structure and evolution.

Between bolometric magnitudes and the **UBV** system, photoelectric photometers and blue-sensitive plates, we have come a long way from naked-eye stargazing on a lovely Aegean isle and Hipparchus' simple system. But the growth in our knowledge of the stars — their nature and character and even their life cycle — has been even greater and is due in part, at least, to our modern, complex magnitude scales.

— *Dewey Schwartzenburg*

The diagram opposite shows the relative brightness of each magnitude as the area of a circle. Each circle has about 2½ times the area of the next smaller one. On this scale magnitudes below 16 are too small to be seen—the photographic limit of a 200" telescope would be a circle one ten-thousandth of an inch in diameter.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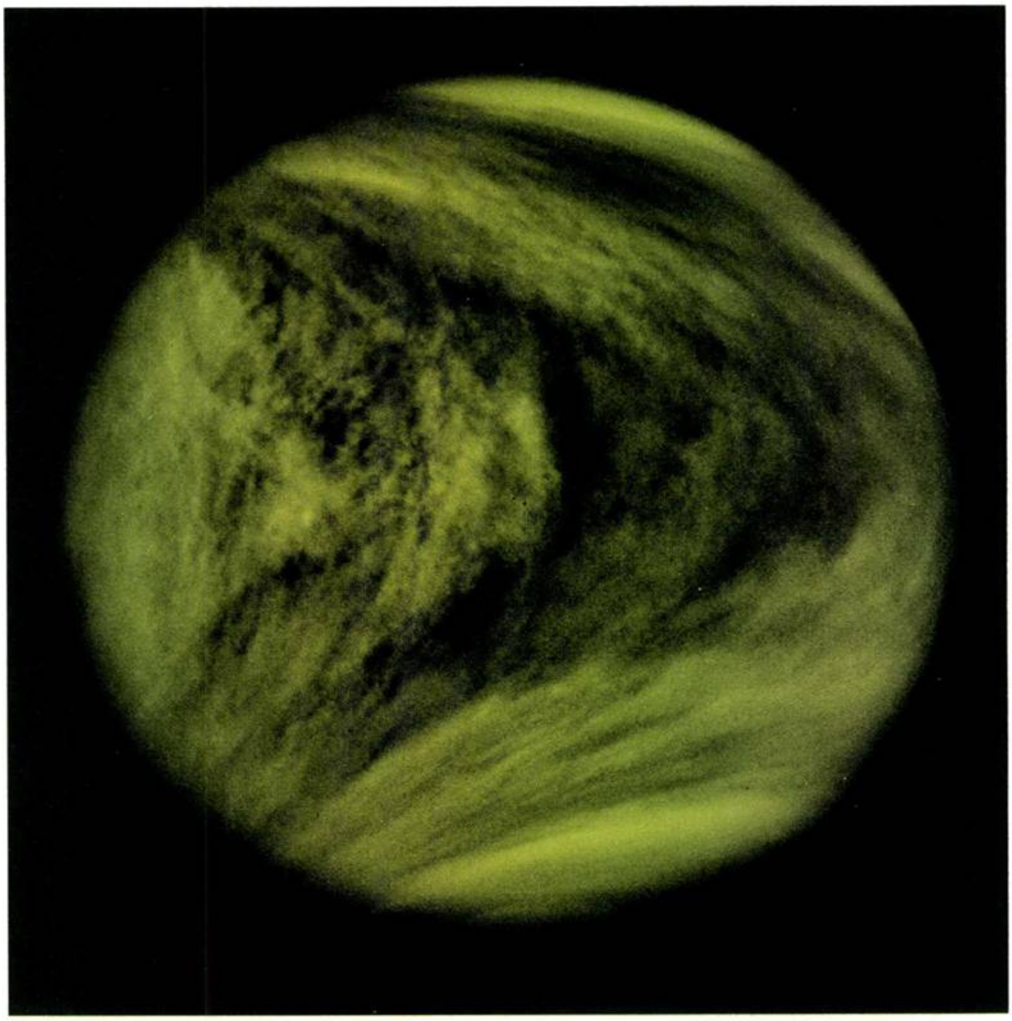
AstroNews

More Pioneer Venus Findings Announced



This photograph, taken by the Pioneer Venus Orbiter on February 19, 1979, is the first close-up ever to show the planet's full disk.

NASA has announced a number of interim findings from the Pioneer Venus Orbiter and Multiprobe missions. The most dramatic is the discovery of the largest canyon yet found in the solar system, a 15,000 foot deep, 900 mile long rift valley which dwarfs even the giant Valles Marineris of Mars. Among the other findings were confirmations of what appear to be periods of virtually continuous lightning in the atmosphere and of a strange constant glow at night near Venus' surface. Also, unique "magnetic rope" structures, perhaps spanning the entire planet, have been found in Venus' ionosphere, and evidence for a large, roughly circular region of downflowing winds over the poles has been gathered. And in a related development, ground-based radar pictures with high resolution have revealed a very large area of Venus' surface which turns out to have a remarkable variety of terrain.

Venus' huge valley is much deeper than similar formations on Earth, where most valleys have been formed by erosion rather than by fault activity. The features on Mars (Valles Marineris) and Venus may indicate that the two planets have undergone much different activity than that experienced by Earth. The canyon's shape suggests to scientists that internal planetary forces have broken open Venus' crust to create the formation, because erosion or the impact of a meteorite would not be likely to cause such a long, linear feature. Also, the Venus canyon is interrupted every 30 to 60 miles by offsets which appear to be similar to the transverse faults in most rift valleys on Earth, such as the Rift Valley of East Africa and the Mid-Atlantic Ridge. Project scientists are still unable to tell just when the venusian fault activity occurred or to what extent the geological forces may still be at work.

The Russian Venera spacecraft found continuous lightning activity during its descent through Venus' atmosphere, with discharges as frequent as an amazing 25 per second. The Pioneer Orbiter also observed this lightning, measuring such discharges during every pass across the planet's night hemisphere. Because of the frequency of the flashes, comparable to the speed of individual frames in a motion picture, an observer on Venus might see the landscape and dense atmosphere bathed in a continuous, eerie electrical glow, accompanied by the roar of constant thunder.

Lightning discharges have also been suggested as a possible source of the "mysterious glow" measured by the two Pioneer nightside probes during their descent. But this appears unlikely,

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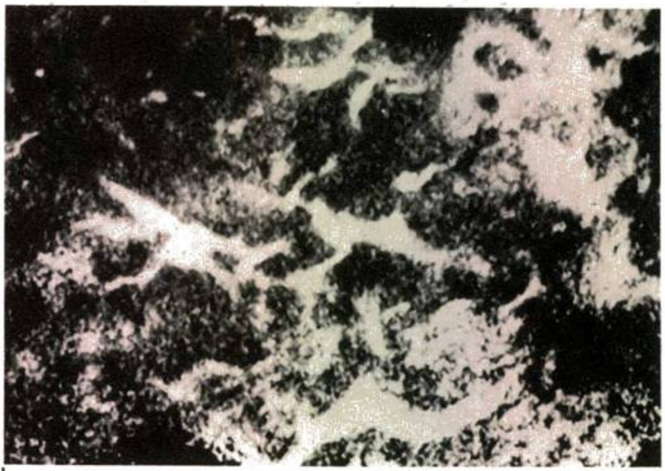


The radar image above shows the region just south of the Alpha feature on Venus. The resolution is about 10 miles, and the photograph covers an area of 2200 by 1200 miles. Apart from the large crater at upper right, most of the structures appear to be huge mountain ranges. Arecibo Observatory/NASA photograph.

since the intensity of the glow increased as the probes approached the surface, the opposite of what would be expected of lightning. Instead, unusual chemical reactions involving sulfur appear to be the source of the strange light. According to Dr. Ronald G. Prinn of the Massachusetts Institute of Technology, complex sulfur reactions taking place at very high temperatures could account for the glow. Dr. Prinn reported his findings at a recent meeting of the American Physical Society, adding that a lot of laboratory experimentation on high-temperature sulfur reactions would be necessary to pin down the exact mechanisms.

The Pioneer Orbiter's infrared radiometer has found both a depression in the clouds at the north pole and an actual 680 mile wide hole where there were few or no clouds. This finding strongly suggests a downflow of atmosphere at the pole. There is also evidence for a planetwide atmospheric flow in temperature measurements made by the Pioneer Sounder Probe at the equator and the North Probe at 60° north latitude.

New probe findings also show that beneath the clouds, Venus' atmosphere is remarkably uniform in temperature and pressure at all latitudes and in both day and night hemispheres. This means that the Venus weather machine is very efficient at distributing heat evenly over the entire planet.

The Pioneer Venus Orbiter has now taken hundreds of pictures of the cloud patterns. These show that Venus' dark markings are below the reflective upper cloud layer and that the clouds near the poles are currently much thicker, and hence ten times brighter than they were during the Mariner 10 flyby in 1974. It now appears that the characteristic planet-spanning C and Y-shaped dark markings are due either to global breaks in the bright, highly reflective upper cloud deck or to massive upwellings of sulfur compounds to altitudes where they can be seen through the thin upper clouds. The pictures also show that one of the planet's characteristic Y-shaped features has moved through the subsolar (Sun-facing) point on Venus' cloud tops, and is therefore not directly tied to the subsolar point. There also appear to be many more circular cells than previously observed, and some new types of cells. These may be convective cells something like Earth's thunderstorms.

The large dark markings are still believed to be due to absorption by elemental sulfur, but the Pioneer atmospheric measurements suggest that sulfur dioxide and sulfur should be found together in the clouds, as part of the atmospheric "sulfur cycle" (something like Earth's water cycle).

Although much more work is needed, scientists now believe the basic sulfur cycle in Venus' clouds goes something like this: sulfuric acid droplets together with liquid and solid sulfur drift down through the clouds heating up as they go. At the bottom of the densest cloud layer (around 29 miles), the material begins to vaporize and split up. The breakdown products, water, sulfur dioxide, oxygen, and various sulfur compounds, then recirculate up through the clouds, where they reform into sulfuric acid and sulfur through reactions that probably involve solar ultraviolet radiation. The absence of free oxygen and water vapor in the upper atmosphere indicates that these two compounds are being removed by vigorous reactions within the clouds.

Unique magnetic field structures have been detected for the first time in Venus' ionosphere by the Orbiter magnetometer instrument. Twisted magnetic field lines, wrapped around each other like woven ropes, appeared as spikes in the data readout charts, sometimes as intense as the built-up solar wind magnetic field outside the ionosphere. Because Venus does not have a magnetic field, the solar wind constantly bombards the top of Venus' ionosphere. When the solar wind collides with the obstacle of this ionosphere, most of it flows around the planet, but the solar wind magnetic field tends to build up at the boundary. Scientists suggest that the solar wind magnetic field may be diffusing through the ionosphere in these twisted, rope-like field lines. Another theory is that the magnetic field spikes observed are induced by the flow of electric current in the solar wind.

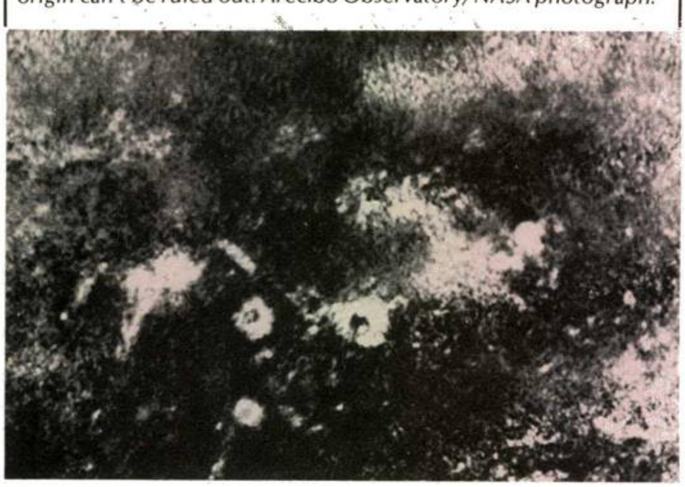
New Earth-based radar observations of Venus' surface show numerous large craters, some 200 miles in diameter. Most of these craters have prominent central peaks resembling many craters on the Moon. As with the lunar craters, the venusian craters seem to be the result of large meteoritic impacts. Most appear to have a blanket of dust on their floors.

Noted many years ago because of its very high radar reflectivity, the area known as Alpha is of special interest. The high resolution of the new observations, made at the Arecibo Observatory near Arecibo, Puerto Rico, reveals that this region, circular and 700 miles in diameter, contains a very large number of roughly parallel ridges about 12 miles apart. Some ridges can be traced for distances of hundreds of miles. The Alpha region appears to have no counterpart on Earth, although it bears some resemblance to the parallel mountain ridges of the Appalachian mountains. A central dark object in this region is suggestive of a large volcano.

Another radar-prominent feature known as Beta is about 500 miles in diameter with long tongues of rough material extending irregularly from it as far as 300 miles. Beta also has a central dark feature, just visible at best resolution, which resembles the caldera of a volcano. Its height may be as great as 6 miles, according to preliminary data.

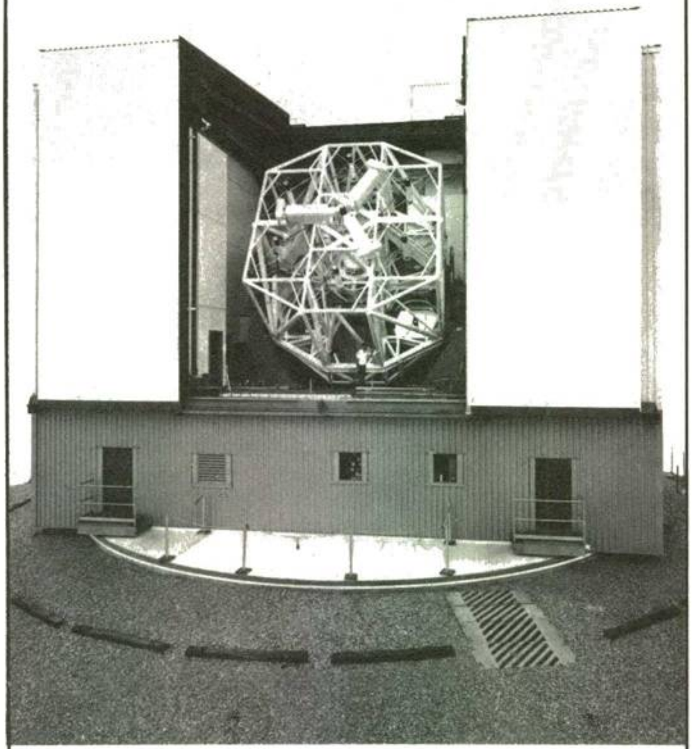
The radar mapping capability aboard the Pioneer Venus Orbiter, in doubt once because of a degradation of data, has been restored completely. Scientists are now examining the long-anticipated "visual" radar images of Venus' surface and comparing them to the Earth-based data from Arecibo.

This ground-based radar image of Venus' surface shows a cratered region just to the west of the large feature known as Alpha. The area covered measures 1400 by 800 miles, and the resolution is about 4 miles. The craters seen are probably due to impacts, but a volcanic origin can't be ruled out. Arecibo Observatory/NASA photograph.



AstroNews

MMT Dedicated



The Multiple Mirror Telescope(MMT), a radically new type of telescope that uses six separate mirrors to create a light-gathering capability comparable to a single 176-inch objective, was dedicated in Tucson, Arizona on May 9, 1979. A major departure in optical telescope design, the MMT is essentially six separate Cassegrain reflecting telescopes, each 72 inches in diameter, working in concert so that the light gathered by each is brought to a common focus.

An electronic control system uses one movable mirror in each of the six systems in combination with laser beams to maintain the six superimposed images in alignment as the telescope changes position in tracking. This sophisticated system is a result of recent technological advances, and has never before been possible.

Now the world's third largest optical telescope (exceeded only by the 200-inch Hale reflector in California and a 236-inch Russian telescope in the Crimea), the MMT may be the prototype of even larger telescopes of similar design in the future.

Once full operation begins later in the year, the MMT will be used primarily for both optical and infrared observations of dim, distant galaxies. Photometric measurements of great sensitivity will enable scientists to study the composition of the surfaces of Pluto and the satellites of Uranus and Neptune. Spectrographic studies of quasars are also high on the priority list. New electronic detectors for producing video images and the spectra of these celestial objects will be used on the telescope.

The MMT dedication events included a banquet and ceremony featuring an address by Senator Barry Goldwater, a special one-day scientific symposium, three public lectures, and the premiere of a documentary movie detailing the conception and construction of the unique instrument. Located on the summit of 8500-foot Mount Hopkins, 25 miles south of Tucson, Arizona, the MMT was built jointly by the Smithsonian Institution and the University of Arizona as a joint federal-state project.

Aldebaran's Girth

The stars are so distant that even the largest telescopes fail to show them as anything other than points of light. However, modern astronomy has indirect ways of determining the diameters of the stars. While these methods are believed to be quite reliable, confirmation by more direct methods is always welcome.

Fortunately, there are direct methods other than observation of an apparent disk. One of the most obvious is when a star is occulted by the Moon or some other body such as an asteroid. Precise observations of the rapid decrease (at disappearance) or increase (at reappearance) in magnitude yield a value for the apparent angular diameter of the star's disk, which, when combined with its distance determined by parallax, gives its actual diameter.

The star which has been most studied in this way is Aldebaran (Alpha [α] Tauri). Aldebaran, with a parallax of 0.048, lies relatively nearby at a distance of 68 light-years, and its position near the apparent path of the Moon causes it to be frequently occulted. Since it is believed to be a red giant with a large true diameter and is rather close, its apparent angular diameter should be one of the largest.

The most recent direct observation of the angular diameter of Aldebaran was made during the occultation of September 22, 1978, by Willet I. Beavers and Joseph J. Eitter of the Erwin W. Fick Observatory at Iowa State University-Ames. Reporting in the March 15, 1979 issue of the **Astrophysical Journal**, they noted that previous measurements of Aldebaran's angular diameter, both by means of occultation and by means of interferometric measurement, gave figures of about 0.02 second of arc. Their own measurements of the reappearance of Aldebaran on September 22 were made in daylight at two different wavelengths of visible light. The fully reduced results indicated an angular diameter of 0.0209 ± 0.0020 second at 7460 Angstroms (A), and 0.0184 ± 0.0021 second at 5680 A. These results are in good agreement with previous measurements, and lead to an approximate diameter for Aldebaran of around 40 million miles — over 46 times the diameter of the Sun.

The researchers also made measurements of the occultation of several bright Hyades cluster members. These led to the first detection of a faint stellar companion to Theta^1 (θ^1) Tauri, estimated to have a visual magnitude of 7.4 ± 0.2. Such a companion, however, cannot be seen from Earth, because it is so close to the primary star — at the time of the occultation the two components were observed just over 300 million miles apart, a little more than three times the distance from Earth to the Sun. The observed angular separation was 0.082 second of arc. Previous researchers had noted on the basis of spectroscopic analysis that Theta^1 Tauri might have just such a companion.

More on SS-433

The mystery of SS-433 (see "Strange Spectrum," AstroNews, June 1979) deepened even as theorists began to tackle the difficult problem of accounting for its peculiar behavior.

The rapidly shifting lines in the spectrum of SS-433 have now been identified, according to Dr. Bruce Margon and his colleagues at the University of California at Los Angeles. There are two separate sets of lines, each one including a complete set of hydrogen Balmer series emission lines along with a weaker neutral helium line. One set shows a massive red shift while the other has a large, but distinctive, blue shift. In addition, there is also a faint spectrum, underlying the two shifted spectra, which shows no wavelength shift at all.

Detailed analysis of nine months of data has also revealed a regularity in the motion of the spectral lines. The pattern of line motions appears to recur with a period of 160 ± 3 days. This periodicity was traced through nearly three complete cycles, but gaps in the data leave some ambiguity about the details. For example, some researchers believe the red-shifted lines and blue-shifted lines exchange places after passing through a phase of zero shift, but this is as yet unproven. The maximum positive and negative velocities represented by the respective shifts are +31,000 miles per second and –19,000 miles per second. These values have thus far been observed to drop to +6000 miles per second and 0 as the two systems of lines move toward each other.

This periodic pattern has been apparently confirmed by E.W. Gottlieb and W. Liller of the Center for Astrophysics in Cambridge, Massachusetts. They examined the blue magnitude of SS-433 as recorded on photographic plates taken over the past several decades and preserved in the Harvard archives. Prior to 1929 they found little indication of periodicity, though there were occasional flares of about half a magnitude. But since 1929 the light-curve cycle has repeated with a period of 161.7 + 0.3 days and a spread of +0.3 magnitude.

Additionally, E.F. Milone of the University of Calgary has reported that infrared observations of SS-433 carried out by T.A. Clark and himself indicate a variability on a time scale of days, and there may even be a smaller variation over a period of hours.

The regular, cyclic motion of the shifted lines, of course, is immediately suggestive of orbital motion, but designing an appropriate model is proving very difficult. R.J. Terlevich and J.E. Pringle of the Institute of Astronomy in Cambridge, England, proposed that an emitting ring of gas in a circular orbit about a central, supermassive black hole could give rise to two sets of emission lines shifted in wavelength by orbital motions. An overall red shift due to the gravitational force of the black hole would account for the asymmetry of the shifts (31,000 versus 19,000). The chief problem with this model is that the lines should be much broader than they actually seem to be.

Another model has been proposed by A.C. Fabian and M.J. Rees, also of the Cambridge Institute. They suggest that an object is emitting material in two opposite jets, a phenomenon familiar from the study of double radio sources. Cooler matter falling in an irregular fashion onto these two jets and being accelerated outwards would give rise to the observed moving emission lines. Instead, it may be that the actual velocity of the beams vary, producing shock waves that spread outwards from the central object. This model, however, has more difficulty in accounting for the apparent regularity in the migration of the lines.

SS-433 (the name comes from its listing in the Stephenson-Sanduleak catalog of stellar objects) is also an X-ray source and a radio source. There is some evidence that its X-ray emission varies over short time scales (less than a day). This adds an additional constraint on theoretical models.

SS-433 is currently being observed closely by many astronomers in an effort to obtain more complete and precise data on its exotic behavior.

Uninhabitable Stars

In considering the possibility of Earth-type life on other worlds, an important factor is the so-called "habitable zone" around a star. This is the region of space within which a suitable planet must orbit if it is to evolve Earth-type life. Within the habitable zone, temperatures on the planet would be neither too high nor too low for life. In particular, the temperature must be high enough to keep most water on the planet in a liquid rather than frozen state, yet not so high as to vaporize the water. In other words, it must be possible for oceans to exist.

Usually the extent of the habitable zone around a particular star has been estimated on the basis of the actual amount of electromagnetic energy (heat and light) reaching a theoretical planet at various distances from the star. This traditional method has led to rather large habitable zones around most stars — very large around bright, massive stars (O, B, and A types), ranging down to narrow around stars dimmer and less massive than the Sun (K and M type stars).

Other considerations (such as the short lifespan of O, B, and A stars and the tidal effects on a planet lying close to late K and all M stars) narrow the choice of suitable stars to F, G, and early K types. The Sun itself is a G2 star — right in the middle of this range. Furthermore, Earth lies right in the middle of the Sun's habitable zone, which according to this traditional method extends from about the orbit of Venus out to the orbit of Mars. It was also for this reason that astronomers once speculated that life might exist on either Venus or Mars, or both.

Unfortunately it now appears that the traditional method of estimating the extent of a star's habitable zone omits significant factors, and these zones are actually much narrower than had been thought. Writing in the January 1979 issue of **Icarus**, Michael H. Hart of the Systems and Applied Sciences Corporation notes that computer calculations demonstrate that if Earth were less than 5 million miles closer to the Sun — a reduction of only 5% in distance — a runaway greenhouse effect such as has occurred on Venus would have taken place about 4 billion years ago, ending the possibility of life on Earth. Furthermore, if Earth's orbit were just 1% larger, at say 94 million miles from the Sun instead of 93 million miles, runaway glaciation would have occurred nearly 2 billion years ago and all Earth's water would have frozen.

Hart has now extended his calculations to other stars, and the computer runs show that for a star 0.83 times the mass of the Sun (a typical K1 star), the width of the continuously habitable zone shrinks to zero. In other words, there is no zone within which climatic conditions suitable for life can endure for a sufficient length of time around stars less than 0.83 solar masses.

The life zone is wider for stars more massive than the Sun, but here other problems appear. For example, stars of 1.1 solar mass or greater emit so much ultraviolet radiation that the spread of life onto dry land is severely limited. Stars heavier than about 1.2 suns (type F7) evolve so quickly that planets close enough to have avoided the runaway glaciation effect invariably become too hot for life by the time 4 billion years have passed. Intelligent life took about 4.5 billion years to evolve on Earth.

Hart concludes that the zone of space around a star within which conditions are favorable for the evolution of life over a continuous period of several billion years is in all cases "fairly narrow," and in any case is limited to stars ranging from F7 through G to K0. If conditions are to remain stable long enough for the appearance of intelligent life, these limits are even further reduced — perhaps meaning that intelligent life can only appear on planets around G-type stars.

Even then, a G-type star would have to have a planet neither too large nor too small, composed of the right elements, located in a fairly circular orbit lying within a few percent of an ideal distance. Earth fulfills all these requirements. The odds that any particular G-type star chosen has such a planet around it are rather small. Thus, on this basis alone, the occurrence of intelligent life on planets of other stars appears to be a much more rare event than had been previously thought. (For other limiting factors, see "Are We the Only Intelligent Life in Our Galaxy?", ASTRONOMY, January 1979.)

Astronomical Doomsday?

To the earliest and most primitive civilizations, meteors were mysterious celestial bodies, a source of awe as they streaked unpredictably across the sky. The motion picture **Meteor**, to be released this month, deals with the danger of a large, asteroid-sized meteor striking Earth. While such a disaster is astronomically possible, scientists agree that the chances of such an encounter are extremely small.

Some recent articles appearing in the popular press have made much of the possibility of *other* natural disasters leading to the doom of mankind. Among the hazards cited are the explosion of a nearby star as a supernova and the occurrence of a solar flare during a period of magnetic field reversal on Earth. But according to Dr. George C. Reid, Deputy Director of the Aeronomy Laboratory in Boulder, Colorado, the danger of the latter two events coming to pass is as minimal as the chance of an asteroid impact.

Concerning solar flares, Reid said that although the Sun frequently produces outbursts, called solar flares, which result in enhanced levels of energetic radiation in Earth's neighborhood, we are shielded from any potentially harmful effects both by the presence of the atmosphere and by the existence of Earth's magnetic field. This field excludes most of the high energy particles from all but our polar latitudes. The Earth's magnetic field is known to reverse its polarity every few hundred thousand years, and it probably vanishes briefly during one of these reversals. The magnetic shield to solar flare radiation would then be removed. Even so, it would take a flare very much more intense than anything astronomers have seen in the last 20 years in order to have any significant effect on Earth life. "We simply don't know if the Sun can produce such super-flares, nor do we know when the next polarity reversal will come," Reid admits, "so we can hardly even speculate about how much risk is involved."

Supernovae, massive stars that explode suddenly and violently when they reach a certain stage in their development, release a tremendous amount of energy. Such explosions, however, are relatively rare, and are believed to occur only at the rate of one per hundred years in the average galaxy. Dr. Reid feels that the chance of a supernova explosion occuring within a dangerous distance from Earth (30 light-years or less) is so minimal that we can expect one only every 100 million years. Since man has been around for about 3 million years at most, we have little to worry about.

Furthermore, none of the stars in the vicinity of the solar system at present have the correct characteristics to become supernovae. Reid did point out that over the 1 billion years or so that life has existed on Earth, nearby supernova explosions may have exerted an influence. Some scientists have argued that the disappearance of the dinosaurs, which occurred within a relatively short period of time all over the Earth and has long been a scientific mystery, could have been due to the intense radiation of a nearby supernova.

Dr. Reid and his colleagues have been performing theoretical studies of potential manmade dangers to the ozone layer of Earth's atmosphere. While their work has not been directly concerned with the occurrence of natural hazards to human survival, the group has considered extreme cases of ozone-layer disasters which might have occurred in the past. The greatest current dangers to human survival, however, are entirely due to human technology.

Instead of Man on Mars...

After the successful Moon landings of the Apollo program, many Americans considered the next logical step in space to be a manned mission to Mars. NASA was even instructed by the Nixon administration to begin planning for this second space spectacular before the mood of the American public and Congress changed and NASA's budget was cut to the bone. According to the **Outlook for Space** study done by NASA in 1975, the total price tag (spread out over a number of years) of a 12 person mission to Mars by the year 2000 would be $32 billion (Apollo cost $24 billion).

Many scientists criticized the United States policy of sending men to the Moon instead of using much cheaper though less sophisticated unmanned probes whose scientific return for the money spent would have been several times that of the handful of Apollo missions. Assuming that a President and Congress were willing to appropriate the $32 billion needed to land men on Mars, what would the same amount of money buy over the next decade in terms of unmanned missions to the planets?

According to **Outlook for Space**, NASA could go on quite a shopping spree with $32 billion. Instead of twelve people journeying to the Red Planet for a brief visit, a Mars Rover, a polar orbiter, and an automated sample return mission could explore Mars for about $2½ billion. With the remaining $29.5 billion, NASA could fund orbiters for the gas giants Saturn, Uranus, and Neptune (the Galileo orbiter/probe mission to Jupiter is already planned). It could also send automated robots to probe the atmospheres of Saturn and Uranus as well as other, more sophisticated machines to rendezvous with Venus, Mercury, the Moon, an asteroid, and a comet and return a sample of each safely to the Earth.

If this sounds like a lot of hardware for not a lot of money, the even more amazing fact is that NASA would have barely dented its bankroll. Space planners would still have enough of the original $32 billion to fund two relatively huge projects: a 12 person, Near-Earth-Orbit Space Station and a 12 person Lunar Base, together costing about $16½ billion. Even after buying these major items, NASA's total tab would still be only $28 billion, leaving enough for such exotic luxuries as a Solar System Escape Spacecraft ($225 million), a lander on Saturn's giant moon, Titan ($800 million), and a 5-6 meter Large Space Telescope that astronomers always wanted but Congress never gave them ($1090 million).

Even after adding these luxury missions, the projected total cost of all the foregoing projects combined would still leave virtually untouched $2 billion in change for unexpected odds and ends like shoelaces and cost overruns. Of course this shopping spree is only an illustrative exercise since $32 billion has not been appropriated by Congress for a crew-operated Mars mission or anything else. What **Outlook for Space** should do is goad Congress into considering some long-range science projects in lieu of sending people to Mars.

A fresh appraisal of our astronomer-ancestors—based on new discoveries in the field of ARCHAEOASTRONOMY

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Edited by Dr. E.C. KRUPP
Director of the Griffith Observatory

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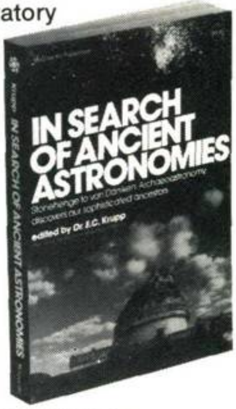

IN SEARCH OF ANCIENT ASTRONOMIES
Stonehenge to von Daniken: Archaeoastronomy discovers our sophisticated ancestors
edited by Dr. E.C. Krupp

Predicting Supernovae

The gigantic stellar explosions known as supernovae are believed to occur in stars much more massive than our Sun when their cores, no longer able to generate enough energy to support the overlying layers against the pull of gravity, collapse catastrophically. This gravitational collapse releases an enormous amount of energy in the form of heat and motion which propagates through the outer layers to the surface of the star. Computer models of such events indicate that it takes between 5 and 20 days for the energy released by a collapsing core to reach the star's photosphere and become visible as a burst of radiation.

It is the burst of radiation from a supernova, quickly rising to a maximum and then slowly decreasing, which is first detected by astronomers. However, because supernovae are such rare events, they have almost never been detected any earlier than peak brightness. Astrophysicists would like very much to have detailed observations of the rapid rise of luminosity in a supernova. Furthermore, some models predict that the optical outburst itself would be preceded by bursts of neutrinos, gravity waves, gamma-rays, and X-rays, and observations of such events would be especially valuable.

As it turns out, there may be a way to predict a supernova explosion even before the initial core collapse. S. Sofia and W.M. Sparks of the Goddard Space Flight Center and A.S. Endal of Louisiana State University, writing in **Nature**, note that the initial collapse of the stellar core which sets off a supernova should be preceded by peaks in neutrino and anti-neutrino emission from the stellar core. Their calculations indicate that a broad peak would occur several months before core collapse, followed by increasingly sharper peaks due to violent thermonuclear events within the dying star. The final and greatest blast of neutrinos and anti-neutrinos would take place about four days before the collapse. (A far greater blast would accompany the collapse itself.)

Throughout this entire period of internal upheaval, the star would appear unchanged on the outside, even to an observer on a nearby planet. Such an optical observer would see a perfectly normal red supergiant, but if he were able to detect the blasts of neutrinos and anti-neutrinos coming from his sun's interior, he would know he had only a few weeks or days to live.

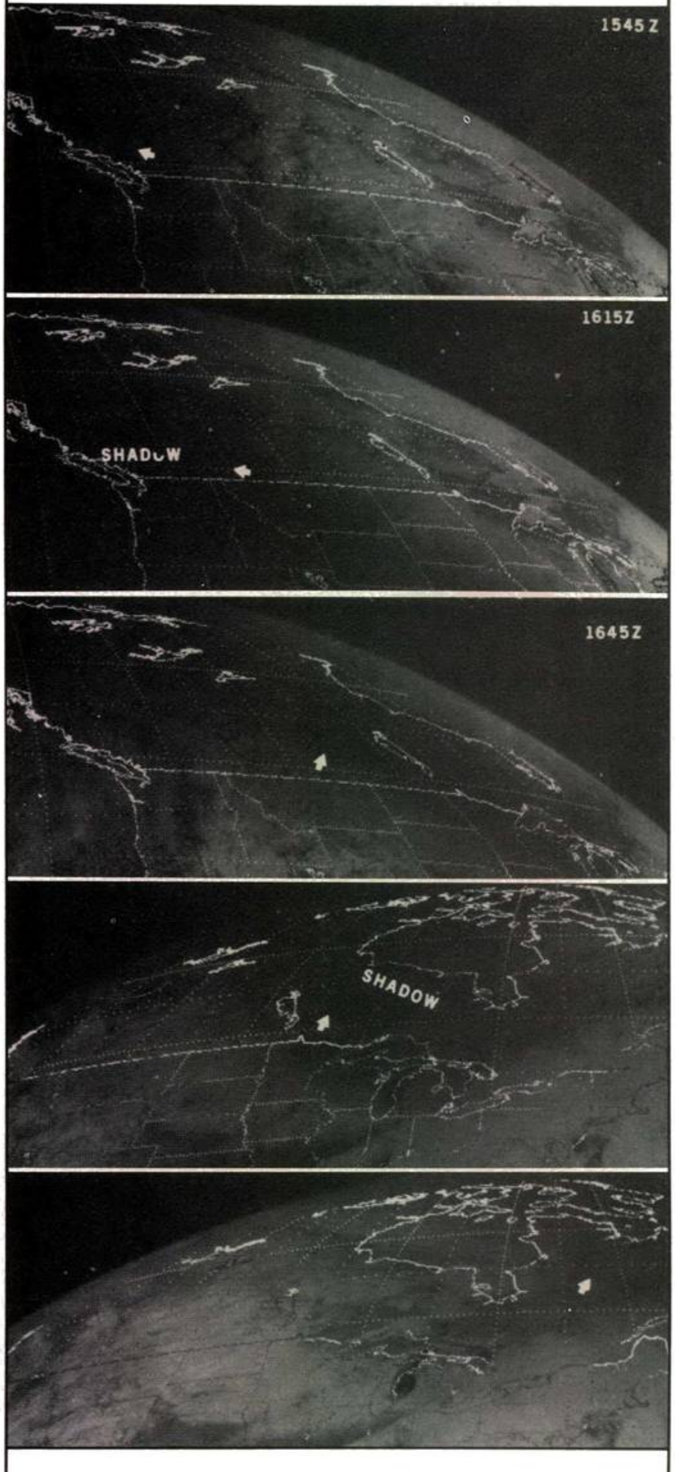
Could such blasts be detected from Earth, enabling astronomers to predict a supernova in advance? Possibly, according to researchers. The main problem is detecting the emission against the background of neutrinos and anti-neutrinos emitted by the Sun and Earth. Their calculations show that the final neutrino blast before the core of a 15 solar mass star collapses could be detected out to a distance of 110 light-years. This distance is not great enough to be of practical use, however, since the probability of a supernova event within 110 light-years of the Sun is (fortunately for us) negligible.

The situation is different, though, for anti-neutrinos. Even though an equal number of neutrinos and anti-neutrinos would be emitted by a dying star, anti-neutrinos would be easier to detect since most of the Sun's emission is in the form of neutrinos. The main background "noise" for anti-neutrinos comes from radioactive decay in the Earth, not the Sun. A dying star could theoretically be detected on the basis of its anti-neutrino emission out to a distance of nearly 5000 light-years.

Unfortunately, this is still not a very great distance when we consider that the diameter of the galaxy is 20 times greater, and supernovae are estimated to occur in our galaxy at a rate of only one every ten years. In order to monitor the entire galaxy, an anti-neutrino detector would have to be placed in orbit far above the Earth to avoid its background noise.

Such a project would be far in the future, though, for in addition to the more mundane problems involved, no one at present has any idea how to design an anti-neutrino detector of sufficient sensitivity suitable for placement in Earth orbit.

Shadow of an Eclipse



On February 26, 1979, people in North America had their final opportunity of the 20th century to view a total solar eclipse within North America. 22,000 miles above the equator the United States' weather satellites GOES-EAST (hovering stationary over the Amazon River) and GOES-WEST (over the eastern Pacific) got a different view of the eclipse. As it moved across the continent, the Moon's shadow appeared clearly in the photographs returned to Earth by the two satellites. Several of these photographs are reproduced above, with the center of the Moon's shadow marked by an arrow. The extensive cloud cover over the United States and Canada on the day of the eclipse can also be seen. Some, however, got their view of the eclipse from aircraft flying above the clouds.

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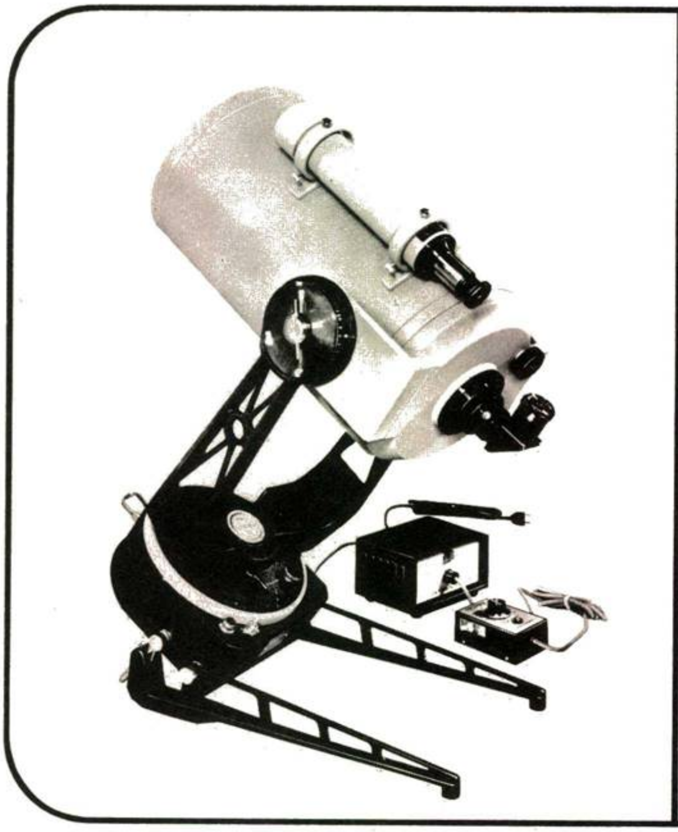

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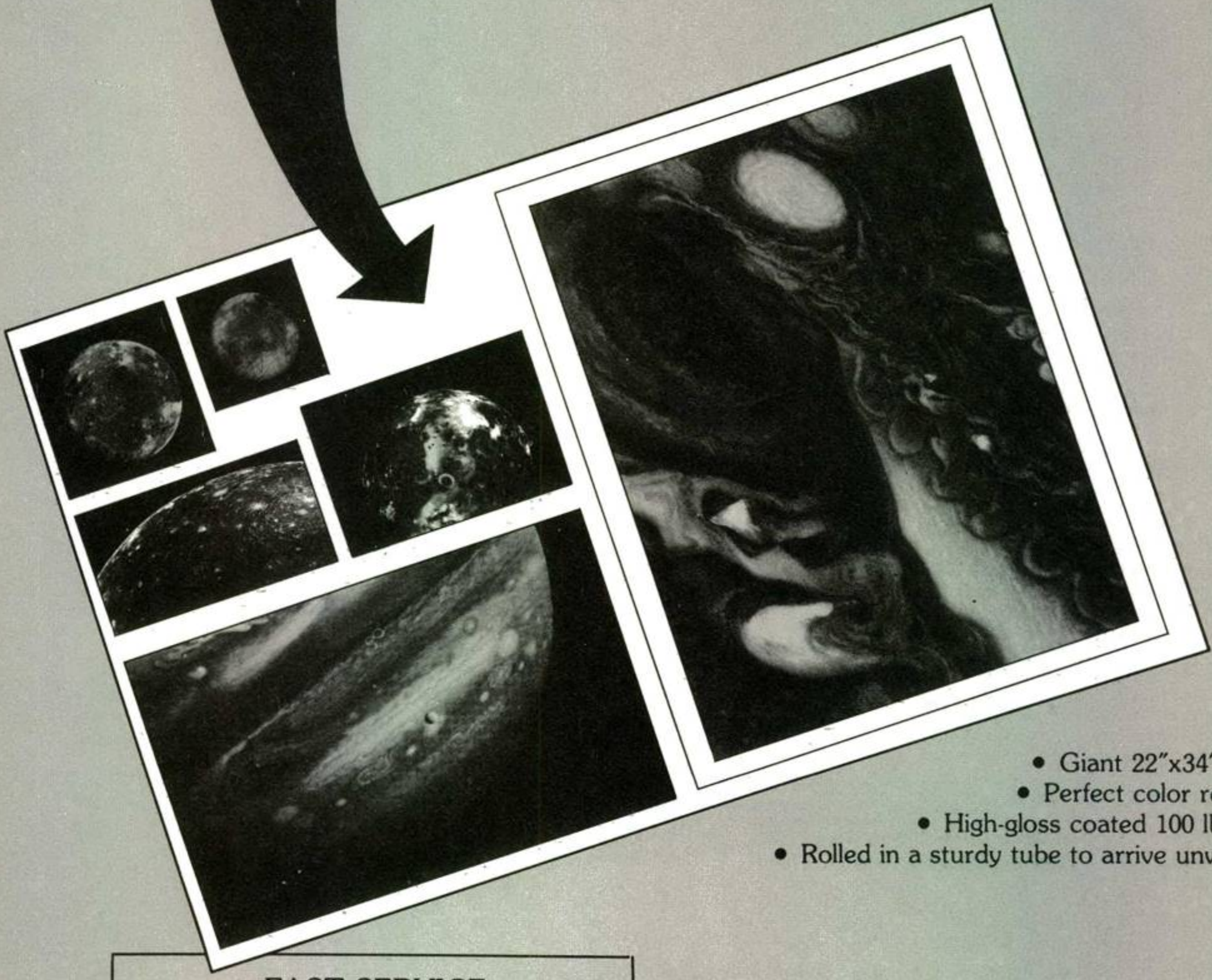

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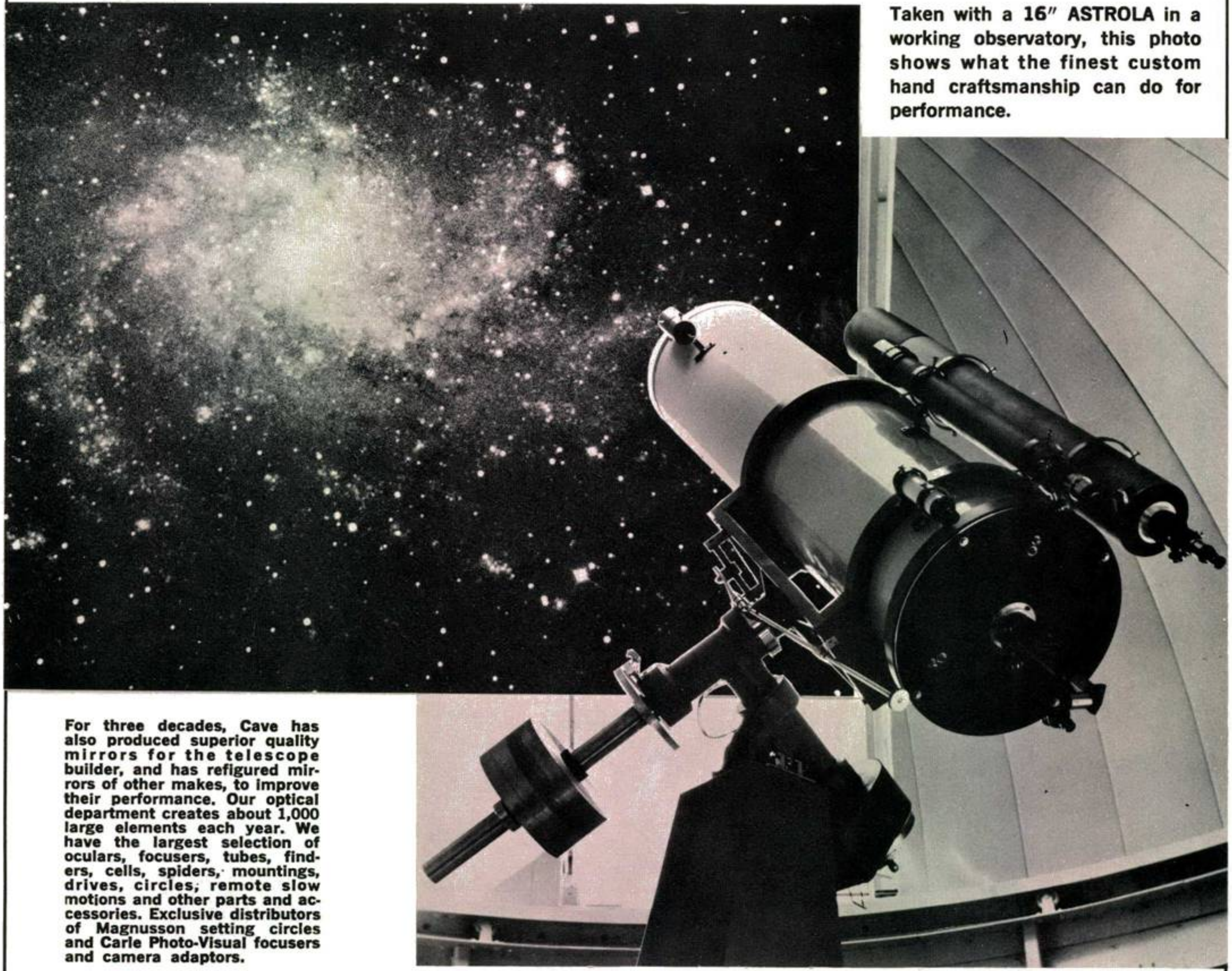

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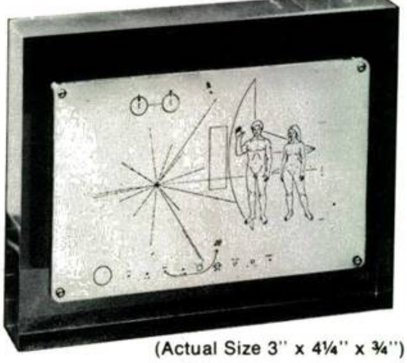

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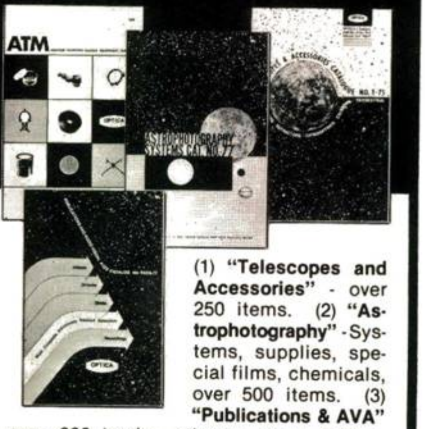

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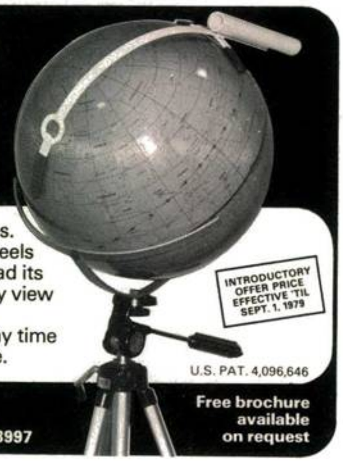

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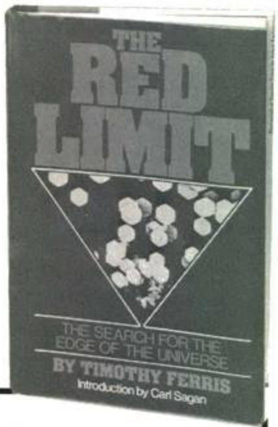
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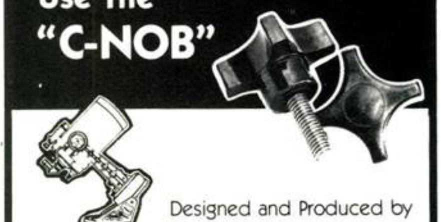

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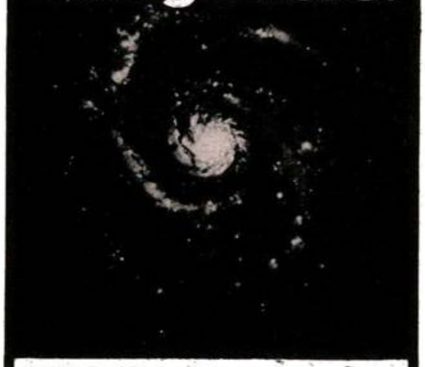

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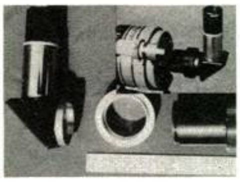

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WANTED — 16mm Brandon 1-1/4" eyepiece, 35mm SLR camera back for astrophotography; major brand (e.g., Nikon, Canon, Olympus). Reasonable prices on equipment in excellent condition. Write John Ettlie, 3152 Harrison St., Evanston, IL 60201.

WANTED — Celestron 5" or 8" reflector telescope. Also all accessories you have; include picture if possible. Also any Star Atlases. Write as soon as possible to Doug Ewasiuk, 10140 Number 1 Rd., Richmond, British Columbia, CANADA V7E 1S2.

WANTED — Correspondence with persons (ages 15-19) interested in space travel, the High Frontier, science fiction, astronomy. Write Bill Farrand, 248 W. Mill Rd., Long Valley, NJ 07853.

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WANTED — Complete information about planets orbiting around other stars, binary stars, and information on Delphinus, Dalfeene, or anything phonetically close to that. Contact Christine Holmes, 3333 Mac All Ct., Napa, CA 94558.

WANTED — Correspondence with anyone having information about how to make camera adapter for telescope. I have a Practina IIa camera and can't find an adapter so need all including focusing information. Write Jim Kellogg, P.O. Box 1629, Grand Junction, CO 81501.

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WANTED — One copy, in good condition, of Proceedings of the First Astrophotography Seminar in March, 1975, hosted by Ventura and Orange County Astronomical Societies. Will pay reasonable price. Contact Emil Volcheck, 1046 Gen. Allen Ln., West Chester, PA 19380. Phone (215) 388-1581.

WANTED — Correspondence with devout amateur astronomers, preferably male (16-?), living in or around Altoona area. Will answer all letters. Contact Pamela S. Wetzel, 709 2nd Ave., Altoona, PA 16602.

INFORMATION WANTED — On eclipse path predictions, weather prospects, accommodations, air fare, maps, tourist attractions, etc. concerning June 11, 1983 total solar eclipse through Indonesia. Contact Nelson Chow, 3557 Golden Orchard Dr., Mississauga, Ontario, CANADA L4Y 3H7.

INFORMATION WANTED — Correspondence with persons, any age, in the Rutherford County area interested in astronomy. Write Phillip Ray, Rt. 1, Box 272, Forest City, NC 28043. Phone (704) 245-9718.

ANNOUNCEMENT — Comet News Service provides you rapid notification of bright comet discoveries, observing information, and reviews of the very latest developments in cometary astronomy. Free for long, SASE. Mail to CNS, 750 Legion, New Haven, CT 06511.

ANNOUNCEMENT — Amateur astronomers and astrophotographers are invited to Astro-Northwest '79, the joint convention of the Astronomical League, Western Amateur Astronomers and Association of Lunar & Planetary Observers, in Portland, Oregon, August 16-19. Address inquiries to 15976 E. Burnside, Portland, OR 97233.

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ANNOUNCEMENT — Classes in all aspects of telescope making are conducted for the public by experienced instructors in New York City. For free information send long, SASE to Optical Division - A.A.A., American Museum - Hayden Planetarium, 81st St. & Central Park West, New York, NY 10024.

ANNOUNCEMENT — Philadelphia based Delaware Valley Amateur Astronomers meet the 2nd Friday of every month at the Schuykill Valley Nature Center in Roxborough. Activities include regular star parties and astrophotography. Contact Ed Kaczanowicz, 434 E. Rockland St., Philadelphia, PA 19120. Phone (215) 457-8470.

ANNOUNCEMENT — Buffalo Astronomical Association meets on the 2nd Friday of each month at 8 p.m. (except July and August). Place: Museum of Science Humboldt Pkwy. or Science Aud. of Buffalo State College, 1300 Elmwood Ave., Buffalo, NY. For information call Carl T. Milazzo, (716) 688-7620.

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ANNOUNCEMENT — Southwest Washington Astronomical Society welcomes anyone in our area interested in astronomy. Contact Carl M. Newton, 2421 Leisure Ln., Centralia, WA 98531. Phone (206) 736-6144.

ANNOUNCEMENT — Call Seattle (206) 324-ASTR.

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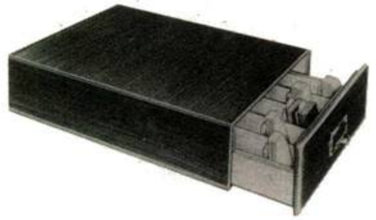

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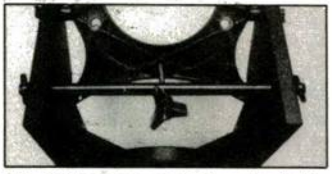

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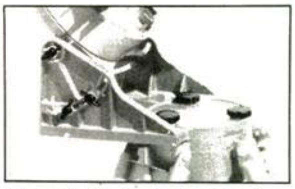

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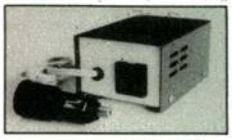

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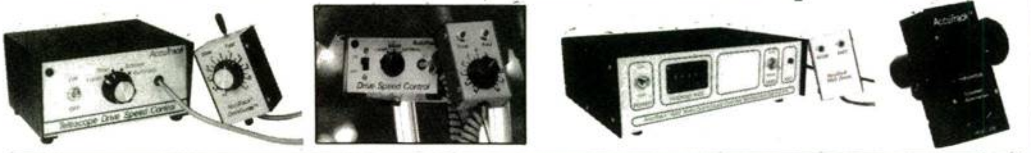

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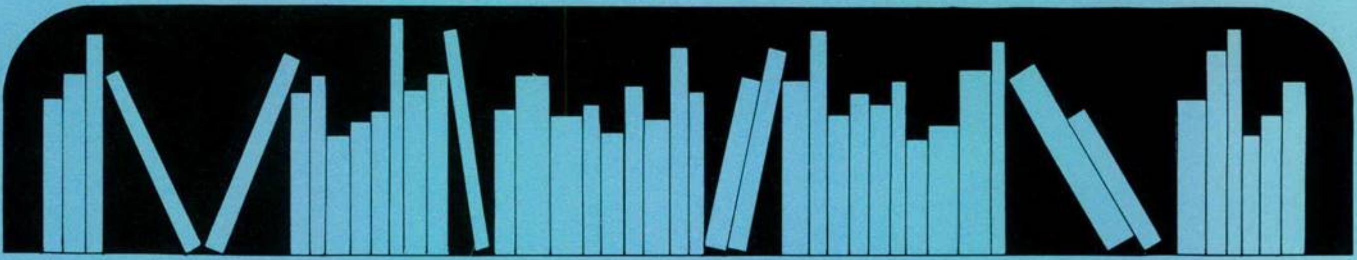

ASTRONOMY REVIEWS

Until the Sun Dies

by Robert Jastrow
172 pages, hardcover, $8.95
W.W. Norton & Co. (1977)

In this attractively produced volume, Robert Jastrow, author of a best-selling astronomy text, makes two major mistakes. The first is that he seeks God in human ignorance. The second, and less forgivable, is that he consistently oversimplifies, often to the point of actual error.

Until the Sun Dies is a badly needed attempt to summarize our knowledge of the origin of life and intelligence on Earth, and speculations on our eventual fate. Jastrow begins by stating that the Bible may be more right than most modern men and women of science have been willing to admit: that the universe did indeed begin with an act of creation. Jastrow justifies this statement by explaining the Big Bang hypothesis of the universe's origin. He makes the religious connection by saying that the Big Bang must have been the true beginning of the universe, not just another in an infinite series of universal expansions and contractions, because the universe does not contain enough mass to cause it to collapse back into itself. He is right as far as he goes, but the idea that the universe is not closed is still only hypothesis. Astronomers have not yet found enough mass to close the universe, but they find more every year, and so it remains entirely possible that they will find enough before they have finished.

The second portion of the book covers the formation of stars and planets with admirable brevity. The author pays particular attention to the Earth, graphically describing the violence of its early days and its first noxious atmosphere, but here he makes one of his errors of oversimplification. Calling the new Earth "a naked body of rock without air or water," he neglects the gaseous components of the solar nebula which would have provided an initial atmosphere, mentioning only the contribution from volcanic fumes.

Jastrow then lays out current ideas about the origin of life. He describes how lightning (and other sources of energy) presumably caused the components of the early atmosphere to react and form amino acids, nucleotides, and other substances essential to life. He mentions how these substances must have come together to form proteins and nucleic acids, and then he jumps to the first living things. He doesn't do justice to the laboratory work that has shown how amino acids can form protein-like compounds under the influence of dry heat and that these "proteinoids" can form tiny hollow spherules closely resembling primitive cells. Instead, he prefers to stress the lack of direct evidence of how life arose, of molecular fossils, and to point out that our theories about the origin of life are founded on faith just as much as is the creationist view. True, the evidence is circumstantial: laboratory experiments have shown how life *might* have arisen. But even circumstantial evidence can be enough to convict a criminal in some cases, so the evidence is more solid than the word "faith" implies.

Jastrow closes out this part of the book by surveying evolution from the first cells to the end of the age of dinosaurs and the coming of the mammals. He oversimplifies here, too — he could hardly help it in 15 pages — by misrepresenting the early multicellular animals, the genetics of evolution, and the dinosaur physiology.

Part three of **Until the Sun Dies** follows the mammals from their origin in the dawn of the dinosaur age to the present. Here Jastrow summarizes the post-dinosaur explosion of mammals into thousands of forms and lifestyles, one of which was that of our own ancestors, the early primates. These small creatures resembled modern shrews, living in trees, eating insects and fruit. Thanks to the demands of their environment, their descendents evolved hands, binocular and color vision, and increased intelligence. Thirty-five million years ago they became monkeys, and the path to humanity was clear. Jastrow overplays the importance of brachiation (swinging by the arms) in human evolution, but in the main, his outline of human evolution is correct. He wraps up this section of the book with accounts of the tools our ancestors used and of the apparent role of climatic changes, beginning a million years ago, in forcing the human brain to double its size and, presumably, its capabilities by a hundred thousand years ago. This doubling was an unprecedentedly rapid example of evolution at work.

The last portion of the book is devoted to an appraisal of the results and implications of our search for extraterrestrial life. Jastrow is willing to bet that the Viking experiments did indeed reveal the presence of life on Mars, and he looks forward confidently both to eventual contact with intelligent aliens and to the further evolution of the human species.

Until the Sun Dies is a short book. It is not free from error or even from a touch of theistic dogmatism. It is not as rich in detail as it might be, but it is a very readable summary of a body of knowledge that more people should appreciate and that is becoming more and more important both to astronomers and to readers of newspapers. Its last chapters amount to a song of optimism about the human future. Don't buy it for yourself if you have taken a few college science courses, but *do* think seriously about gifting a young relative with it. You might even send a copy to your congressman; it could spark a lifelong commitment to science. *Thomas Easton.*

◆

Burnham's Celestial Handbook
by Robert Burnham, Jr.
2138 pages, softbound in three vols.
Dover Publications (1978)
(Available from ASTRONOMY for $9.50 each, postpaid)

This monumental three-volume tour guide of the heavens is the most significant publishing event in the field of deep-sky observing since the appearance more than a century ago of Webb's classic work, **Celestial Objects for Common Telescopes**. Compiled by Robert Burnham, Jr., a staff member of the Lowell Observatory in Arizona and discoverer of comet Burnham in 1959, the set is a revised and enlarged version of the author's privately published 1966 loose-leaf edition.

Subtitled "An observer's guide to the universe beyond the solar system," the **Handbook** is intended primarily for visual observers using 2-inch and 12-inch aperture telescopes. Arranged by constellation, volume I covers Andromeda through Cetus, volume II Chamaeleon through Orion, and volume III Pavo through Vulpecula. Spanning more than 2,000 pages, the three volumes together include well over 7,000 deep-sky objects of interest to amateur astronomers.

The first volume opens with a survey of the astronomical universe, followed by a valuable section on fundamental knowledge for the observer and, lastly, a discussion of the arrangement and use of the **Handbook** itself. Each constellation begins with extensive tables of double, multiple and variable stars, clusters, nebulae, and galaxies lying within their boundaries. These are followed by detailed descriptions of selected objects including many of the brighter stars in each group having special interest. Each volume is profusely illustrated with finder charts, diagrams, graphs, drawings, and photographs, most expressly prepared for this project and never before seen in print. Through his effort, the author has in essence made it possible for anyone to have a well-equipped resource library in their own home.

The **Handbook** is not merely a vast compilation of astronomical facts and statistics, but rather reads like a celestial travelog. Burnham is an observer of long standing and his intimate familiarity with the night sky is reflected throughout these volumes. Even when factual material is presented, it is often done so in novel ways. As one example, the author points out the incredible fact that to count the number of miles in a single light-year (about six trillion) would require more than 150,000 years. But the descriptions of various deep-sky objects are what really breathes life into the **Handbook**, making it reminiscent of those in the tradition of Smyth, Webb, and Barns.

Burnham's approach to observing is a much-needed aesthetic and philosophical one, and as a result, the book is spiced with many quotations and passages. This can be sensed even in the opening pages, where he calls attention to two aspects of our hobby that every star lover should recognize. The first is that "considered as a collector of rare and precious things, the amateur astronomer has a great advantage over amateurs in all other fields, who must usually content themselves with second and third-rate specimens ... in contrast, the amateur astronomer has access at all times to the original objects of his study; the masterworks of the heavens belong to him as much as to the great observatories of the world. And there is no privilege like that of being allowed to stand in the presence of the original."

The second point concerns the distorted view many people hold of astronomers as escapists from reality. Burnham sets the record straight — and in so doing calls attention to one of the very real personal values of stargazing — by replying: "Contemporary civilization, whatever its advantages and achievements, is characterized by many features which are, to put it very mildly, disquieting; to turn from this increasingly artificial and strangely alien world is to escape from unreality; to return to the timeless world of the mountains, the sea, the forest, and the stars is to return to sanity and truth."

If you call yourself an observer — whether beginner, seasoned, or just an "armchair" enthusiast — you ought to have these three volumes. *James Mullaney.*

NEW BOOKS

Space Shuttle and Spacelab Utilization
edited by George W. Morgenthaler and Manfred Hollstein
820 pages, 2 vols. (illus.), hardcover, $70.00 a set
American Astronautical Society (1978)

These two volumes document the meeting held in March 1978 on the use of the Space Shuttle and Spacelab. If you are interested in what scientists plan to do with the Shuttle during the next decade, you should at least browse through these two volumes. The level of presentation ranges from semi- to very technical, but even a lay reader can get a clear idea of what's going on.

The Creation of the Universe
by David E. Fisher
119 pages, hardcover, $8.95
Bobbs-Merrill (1977)

Now in its third printing, David Fisher's book takes the general reader on a leisurely and entertaining tour of cosmological theory, chiefly dealing with relativity. The book has suggestions for further reading and an index.

In the Center of Immensities
by Sir Bernard Lovell
172 pages, hardcover, $10.95
Harper & Row (1978)

The "immensities" of the title refer to the expanding cosmos which has been a part of our intellectual heritage for the last five centuries. The expansion was metaphorical at first, but in the last 50 years, has become physical as well. The presentation by the well-known British radio astronomer is for the general reader.

The Nature and Origin of Meteorites
by D.W. Sears
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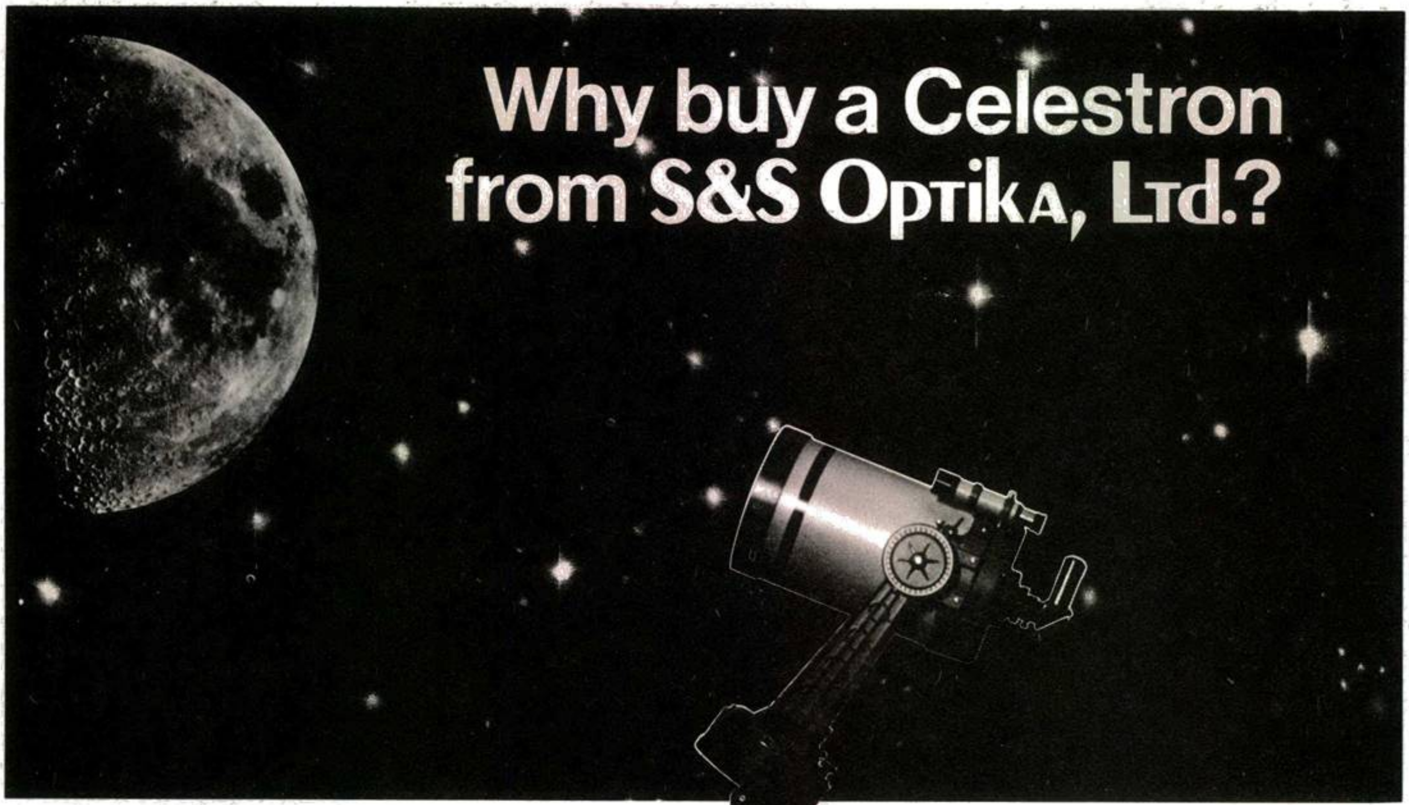

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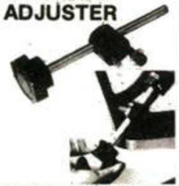

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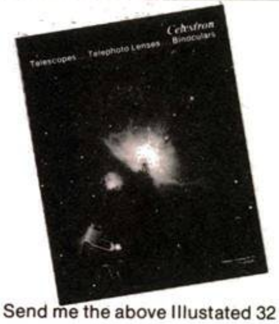

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JULY

by
Dewey Schwartzenburg
and
James Mullaney

The tenth anniversary of the first manned landing on the Moon comes in an especially appropriate year, for 1979 is turning out to be one of the most spectacular years for space exploration in the last couple of decades. Three planets in particular are the focus of this year's activities: Venus, Jupiter, and Saturn. Even though the Russian and American atmospheric entry probes reached Venus last December, it was during this year that the final results of these missions became generally available. Furthermore, the Venus orbiter has been conducting a continuous surveillance of our closest neighbor since then.

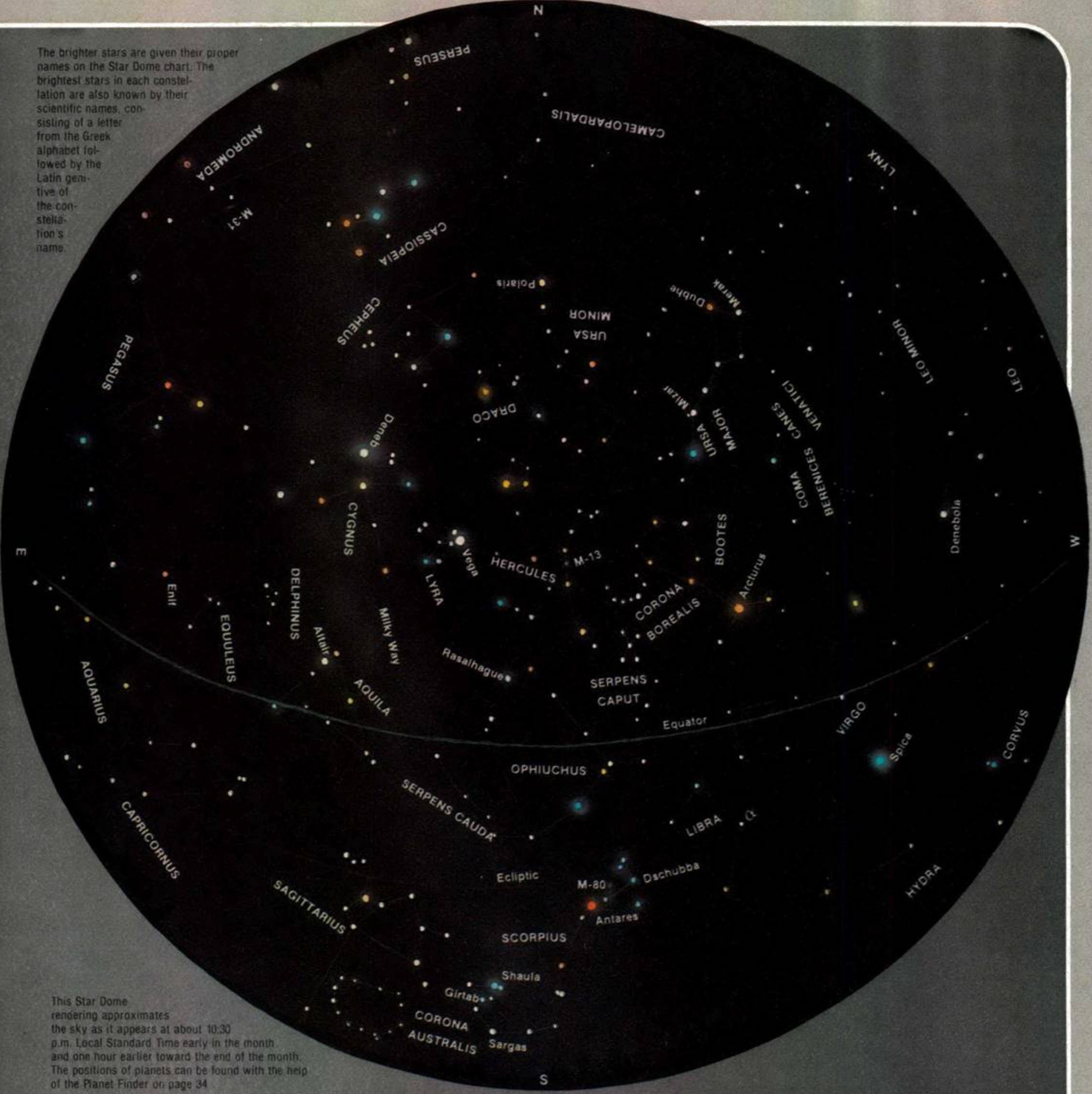
But it is the giant outer planets, Jupiter and still-to-be-visited Saturn, which are providing most of the year's anticipation and excitement. The first Voyager spacecraft reached Jupiter early last March and amazed the world with its revelations about the huge, complex jovian system. More will certainly be learned when Voyager 2 reaches Jupiter early this month, just short of exactly ten years after the Apollo 11 landing. Continuing the year's scheduled program of space spectaculars with a seemingly excellent sense of timing, Pioneer 11 will arrive at Saturn in early September.

In exploring the outer planets, we are indeed exploring the giants of the solar system. Jupiter alone constitutes nearly 2½ times as much mass as that of all the other eight planets combined. The four gas giants together amount to 445 times the mass of Earth, while the total mass of everything in the solar system outside the Sun is only a little over 447 earth masses. In other words, about 99½% of the mass in the solar system outside of the Sun is found in the four planets Jupiter, Saturn, Uranus, and Neptune. (The Sun itself, of course, totally dominates its family with its enormous mass of 332,830 earths — 99.9% of the total mass of the solar system.)

It has been truly said that a fair way to describe the solar system is to say that there are just four planets — along with a little debris! It may be surprising to discover, for example, that the total mass of all the satellites in the solar system amounts to only 0.12 the mass of Earth. And those who like to believe that the asteroids are the leftover pieces of some ancient exploding planet may be disappointed to learn that their cataclysmic planet was only 0.0003 the mass of Earth — a very tiny planet indeed! Comets, meteoroids, interplanetary gas and dust, and everything else in the solar system outside the Sun, the nine planets, their satellites, and the asteroids, manage to contribute an infinitesimal 0.000000001 earth-mass to the total — one-billionth of our planet's mass.

Our exploration of Jupiter and Saturn, therefore, represents in a sense the beginning of our exploration of the solar system as a whole. One result could very well be a profound change in our perception of ourselves and our place in the cosmos as we realize what a tiny place Earth is after all, even in our own solar system.

Those who belittled the manned Moon landing as "spending billions of dollars to put some clown on the Moon" failed to recognize that that achievement was symbolic of a process of human advancement having tremendous impact on our life right here on Earth, and not least in the area of our self-understanding. The spirit of that early period of the space age was symbolized by that amazing image of Earth from space: a beautiful blue-green globe streaked with white floating in the peace and quiet of interplanetary space. We were reminded of our essential togetherness as fellow inhabitants of "Spaceship Earth," a term and concept which entered the language along with that image. The exploration of near-earth space led us to look back on ourselves, and helped fire the new concerns of environmental protection and resources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The brighter stars are given their proper names on the Star Dome chart. The brightest stars in each constellation are also known by their scientific names, consisting of a letter from the Greek alphabet followed by the Latin genitive of the constellation's name.

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month and one hour earlier toward the end of the month. The positions of planets can be found with the help of the Planet Finder on page 34.

conservation here on Earth.

This phase of the space age is now drawing to a close, and we are standing on the threshold of a new self-perception and awareness. Despite all the budget cutbacks and the decline of media excitement, the expansion of our consciousness outward from this planet has resumed. Giant Jupiter and ringed Saturn may soon replace the globe of Earth as central cultural symbols of our time, and along with that change will come a new outward-looking perspective. It may be that the first phase of space exploration in any intelligent civilization must be accompanied by an introspective period as that world contemplates the meaning of its essential oneness and place in the universe. But for us as for all worlds, that introspection, that preoccupation with things terrestrial arising from the newness of seeing ourselves from the outside, must sooner or later give way to a larger perspective.

This may be the gift the giant planets Jupiter and Saturn are about to bestow upon us in this year of 1979. This has become a year in which our attention is inexorably drawn to the heavens again and again by news of some new wonder discovered there. Future historians may see it as the year in which a new cultural perspective was born, when we first began to look up at the night sky with an entirely new awareness of its meaning.

Close-Up

Vega

Webb introduced his faithful readers to the tiny but thrilling Lyra region by noting: "for its size, one of the most remarkable constellations, full of beautiful fields, and adorned by one of the great leaders of the firmament." The object referred to is, of course, Vega — Alpha (α) Lyrae — that dazzling blue-white diamond which ranks as the brightest star in the

northern heavens. Passing nearly overhead on summer evenings, it rules the sky like some lone monarch in isolated splendor. And because of its high declination, it is visible at some hour most every clear night of the year, making it a constant companion of the stargazer.

This "arc-light of the sky" is a zero-magnitude A-type sun whose electrifying radiance requires 26½ years to traverse the distance from the star's hot surface to our eyes. In large refracting telescopes (12-inches or more in aperture) having a slight "blue excess" in color correction, Vega appears nearly pure blue with flashes of deep violet and purple flooding the field — truly an amazing and unforgettable sight.

Most inspired of all the classic descriptions of this object has to be that left by Barns, who felt Vega "resembles an old-mine Brazilian brilliant of purest water intensified to infinity!" A more reserved account was given by Webb: "to my sight inferior to Sirius only...Its colour to me pale sapphire — a lovely gem."

Aside from its stunning hue, Vega is also of interest as a double star having a 10th magnitude optical companion nearly due south (position angle 173°) of it at a distance of 63 seconds. Although difficult to see against the blaze of the primary with much less than a 4-inch glass on a typical night, this object presents a fine magnitude contrast in 6-inch and larger apertures. Muirden listed it as bright as 9th magnitude while others have given it as faint as 11th.

This little star has been glimpsed with less than 2 inches of aperture. Webb himself saw it as "smalt blue" in color, while Bernhard, Bennett, and Rice gave it as orange. There are several other fainter objects lying near Vega including an 11th magnitude one, 54 seconds from it near position angle 285°. How many of these can you detect with your telescope on a steady, transparent night?

Vega is of considerable historical importance, for in ages past it served as the pole star — a prestigious role it will again assume some 12,000 years from now as a result of the Earth's slow precession on its axis. More recently, this star was the very first ever photographed (aside from the Sun) — a feat accomplished at the Harvard

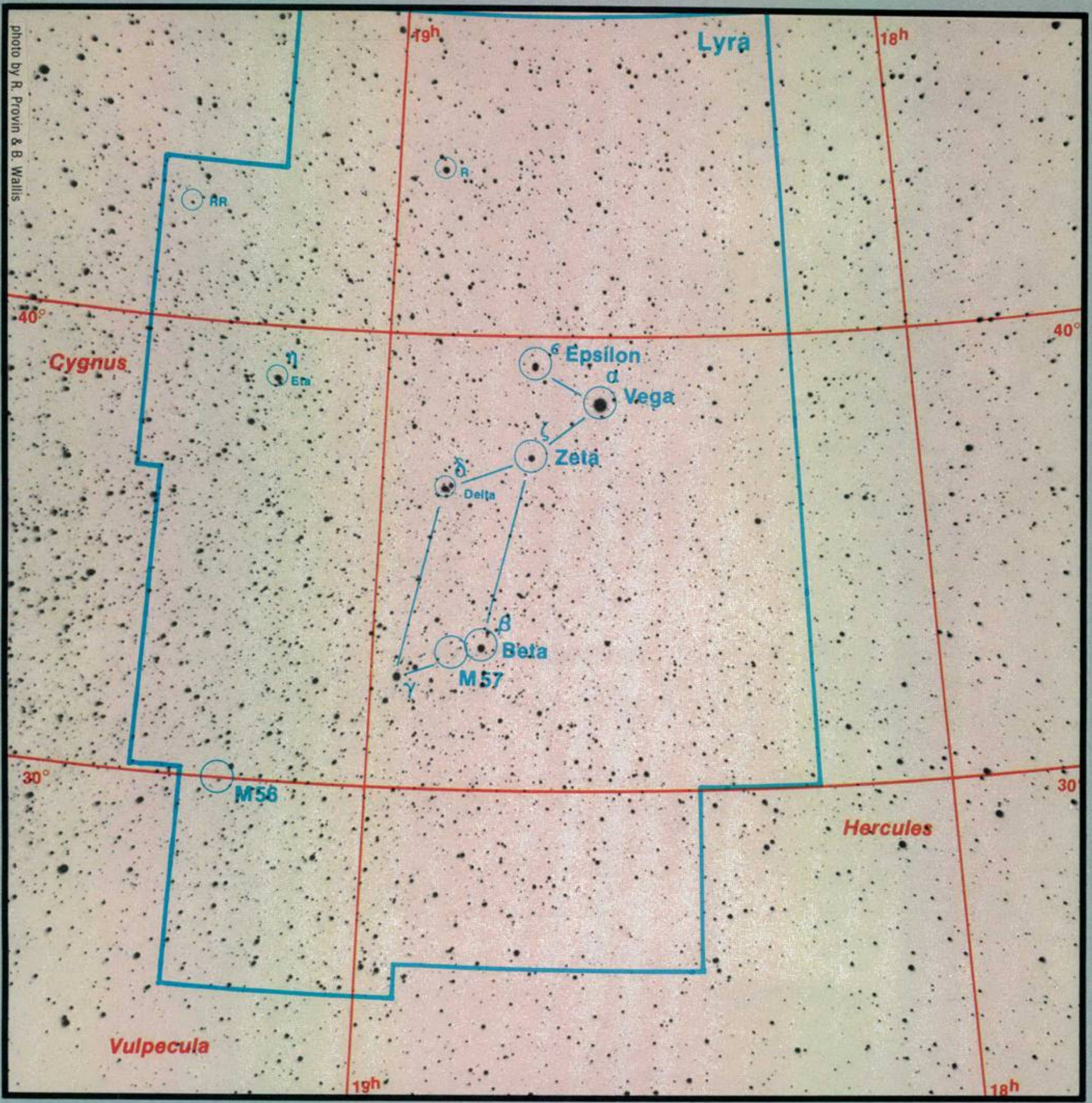


photo by R. Provin & B. Wallis

College Observatory back in 1850.

Epsilon (ε) Lyrae

Just 1½° northeast of Vega is the quadruple system Epsilon (ε) Lyrae — better known as the "double-double." Discovered by Sir William Herschel in 1779, the exquisite foursome ranks as the finest multiple star in the northern sky for small telescopes. Smyth described the scene here as follows: "the naked eye sees an irregular-looking star near Vega, which separates into two pretty wide ones under the slightest optical aid. Each of these two will be found to be a fine binary pair."

Beginning observers should note that the separation between Epsilon's two pairs is 3½ minutes of arc, for this object is often confused with nearby Zeta Lyrae (see below) which lies 1½° southeast of Vega. Both appear double in binoculars and finders, and have components of roughly the same brightness and in the same position angle. However, those of Zeta are less than a minute apart, and no amount of magnification on any telescope will show the components as double stars.

The double-double consists of a northern pair (Epsilon^1) of 5.4 and 6.5 magnitude stars currently 2.8 seconds apart, and a southern one (Epsilon^2) having 5.1 and 5.3 magnitude components now 2.6 seconds distant. Their respective position angles are 360° and 100° (or nearly at right angles to each other on the sky), and the pairs themselves are 208 seconds from each other in position angle 173°.

The four members of the Epsilon clan are resolved with just 75 to 100 power with a good 2.4-inch (60 mm) refractor, and are a stunning sight in 4-inch and larger scopes. Brown claimed that "you will need about 200 power for a clean split without notching," but this depends on the aperture used. For some strange reason, these duos seem relatively insensitive to seeing conditions (image steadiness) as compared with other close pairs having similar separations. All four components are early A-type suns and look white in color to most observers. However, other tints have been reported — especially for Epsilon^1, whose members have been described as greenish-white and bluish-white, as well as yellow and red or ruddy. Muirden stated "all four stars are white except the 6.5 which is bluish." How do you find them?

The double-double is all one vast gravitationally-linked system, the Epsilon^1 pair completing an orbit every 600 years and Epsilon^2 every 1200 years. In addition, the two binaries are drifting through space together and slowly circling a common center of gravity in a period on the order of a million years. There is also present an unseen spectroscopic member in the northern duo, which means there are at least five suns here — all some 200 light-years from us.

Olcott spoke for most in calling Epsilon Lyrae a "marvelous object." It appears on just about everyone's list of deep-sky showpieces, including Pickering's famed roster under finest multiple stars. If you're new to astronomy and haven't yet seen it, you have a real surprise in store for you the next clear night.

Zeta (ζ) Lyrae

As mentioned above, an "impostor" of our last object lies near Vega, forming an equilateral triangle with it and Epsilon. This is Zeta (ζ) Lyrae, marking the northwestern corner of Lyra's parallelogram. Its 4.3 and 5.9 magnitude components are relatively fixed at a wide 44 seconds separation in position angle 150°, forming an attractive and contrasting pair for low powered instruments.

Zeta appears on many double star lists, including Colas' list of the finest colored stars where its tints are given as yellow and green. Bernhard, Bennett, and Rice called them yellow-green and white, and mentioned three other faint companions, while Muirden's account was "white and creme; fine low power object." Still other impressions are reddish and blue-green (Brown), topaz and green (Olcott), and pale yellow and lilac (Franks). The spectral types of primary and attendant are A0 and F0, respectively, and the former is a spectroscopic binary with a period of 4.3 days.

Beta (β) Lyrae

Some 6° below Vega, marking the southwest corner of Lyra's parallelogram, is 3rd — but sometimes 4th — magnitude Beta (β) Lyrae, a multiple star whose primary is an exciting and complex eclipsing binary system.

Beta's light output varies from 3.4 to 4.1 magnitude in a period of nearly 13 days. These fluctuations are easily followed with the unaided eye by making nightly comparisons with surrounding stars like nearby Gamma (magnitude 3.2). This star's variability was, in fact, discovered in the 18th century without a telescope by the English amateur astronomer John Goodricke who, without optical aid, also first determined Algol's light curve, period, and the reason for its changes in brightness.

The light curve of Beta Lyrae displays two unequal minima separated by two equal maxima — variations caused by the mutual eclipse of two unequally bright suns in a very close orbit; the stars are ellipsoidal in shape due to huge gravitational tidal distortions. In eclipsing pairs like Algol and Beta Lyrae, we are actually witnessing, with no more equipment than the human eye, the revolution of two distant suns about each other.

Beta Lyrae is under intensive worldwide scrutiny by astronomers and astrophysicists because its components are known to be losing mass and undergoing evolutionary changes right before our eyes. So vital is an understanding of this system that the famed astronomer Otto Struve — who made a lifelong study of this object — once half-seriously proposed that a 100-inch telescope be built expressly for a program of continuous photometric and spectroscopic monitoring of its highly complex behavior.

Selected Objects — Lyra

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.
*Vega	★^{2}	0,10	63″	18^{h}35^m	+38°44′
*Epsilon (ϵ)†	★^{4}	5.4,6.5+5.1,5.3	2.8″,2.6″	18^{h}43^m	+39°37′
*Zeta (ζ)	★^{2}	4.3,5.9	44″	18^{h}43^m	+37°32′
*Beta (β)	m★	3.4-4.1,7.8,9.9	13^d,46″,69″,86″	18^{h}48^m	+33°18′
*M-57	■	9	83″x59″	18^{h}52^m	+32°58′
Delta (δ)	★^{2}	4.5,5.5	12′	18^{h}53^m	+36°50′
R	m★	4.1-5.0	46^d	18^{h}54^m	+43°53′
Eta (η)	★^{2}	4.5,8	28″	19^{h}12^m	+39°04′
*M-56	●	8.2	3′	19^{h}15^m	+30°05′
RR	m★	7.1-8.0	0.6^d	19^{h}24^m	+42°41′

*Detailed in Close-Up

†Pairs separated by 208″

★ Star
★^{1} Bright Star
★^{2} Double Star
★^{3} Triple Star
m★ Regular Variable
n★ Irregular Variable
H★ Eclipsing Variable
○ Open Cluster
● Globular Cluster
■ Planetary Nebula
□ Bright Diffuse Nebula
§0 Elliptical Galaxy
§S Spiral Galaxy
§/ Barred Spiral Galaxy
§# Peculiar/Irregular Galaxy

Aside from being a fascinating variable star, Beta Lyrae is also a neat multiple system for visual observers. It has a 7.8 magnitude companion 46 seconds from it (position angle 150°), and two fainter 9th magnitude ones at 69 seconds (318°) and 86 seconds (19°). Together, these form a beautiful little triangle centered on the primary star itself.

In a 2 or 3-inch glass at 30 to 45 power, Beta at first glance appears to be a pale yellow and deep blue double, but averted vision immediately reveals the two fainter stars. In 6-inch and larger scopes at 50 to 100 power, all four components are easily seen, transforming this object into a quadruple star having exquisite symmetry. Despite this, Barns listed Beta as only double in his 10-inch reflector.

M-57

Slow sweeping of the gap between Beta and Gamma (γ) Lyrae — about 1/3 the distance from the former to the latter — with a low to medium power eyepiece on the telescope will show a small grey globe of light. This is M-57 — the well known Ring Nebula and the finest representative of its class in the northern sky. Its 83 by 59 second elliptical disk is larger in apparent size than Jupiter, and at 9th magnitude it is among the brightest of all planetary nebulae.

The central hole in M-57 can be glimpsed in even a 2.4-inch glass at about 60 power and becomes obvious in a 3 or 4-inch at 75 power. With 6 and 8-inch apertures, differences in the brightness of various parts of the ring are evident, as well as a faint luminous glow within the opening itself (best seen by comparing it to the surrounding sky background). In 10 and 12-inch scopes, this object looks much as it does in black and white photos. The nebula is in reality a bubble or shell, the ring aspect resulting from looking through a greater thickness of gas around the edge than in its center.

Webb pointed out that M-57 is "somewhat oval and bears magnifying well. Its light I have often imagined fluctuating and unsteady, like that of some other planetary nebulae; an illusion arising probably from an aperture too small for the object." This flickering is especially obvious in 3 to 6-inch instruments with averted vision. If Webb's explanation is correct, this effect should diminish in large amateur telescopes — something the well-equipped observer might like to verify for himself.

Barns considered M-57 "finest of the annular type. With high power, ring becomes a globe of luminous gas, receiving its effulgence from a central star. A cardinal unit." Muirden called it "a remarkable object; an annular planetary nebula, bright, bluish and slightly elliptical." Brown stated "looks like a big smoke ring in the sky...not impressive in a small telescope but even a 3-inch at 120 power will show the central hole."

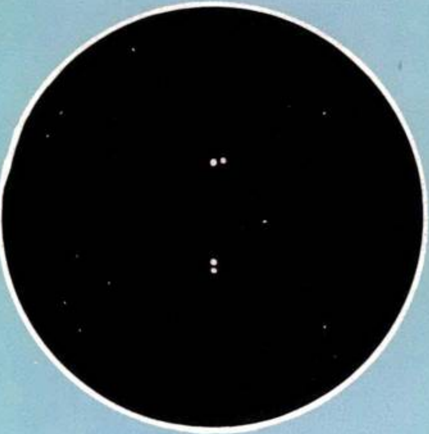
M-57 is on everyone's roster of favorite celestial showpieces — except Flammarion's! (Its omission was obviously an oversight, for this great French observer discussed the Ring Nebula at length in his classic book on astronomy.) William Herschel regarded M-57 as "among the curiosities of the heavens...a nebula that has a regular concentric dark spot in the middle...and is probably a ring of stars." Secchi actually thought he had achieved resolution of the nebula, finding it composed of "minute stars, glittering like silver dust." (These observations were penned at a time when all nebulae were thought to be simply unresolved clusters of stars at remote distances.) John Herschel saw the central hole "filled with a feeble but very evident nebulous light: like gauze stretched over a hoop."

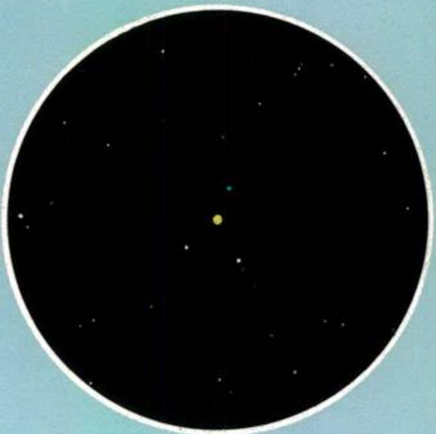
The lengthy account of M-57 by Robert Burnham, Jr. states in part: "a 6-inch telescope is usually needed to see the 'ring' appearance clearly, and fairly high powers may be used since the surface brightness is high. With a good 6-inch or 8-inch glass the nebula strikingly resembles a 'tiny ghostly donut'...The peculiar color, a soft bluish-green, becomes increasingly evident with larger apertures."

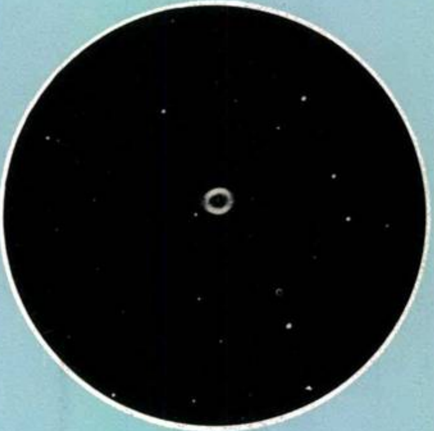
Olcott described M-57 as "a perfect ring of nebulosity in the center of which gleams a 15th magnitude star." Photos often show this elusive object but it is extremely difficult to see visually. It is a hot blue dwarf whose short wavelength radiation causes the ring to glow. Of about 14th magnitude photographically, it is at least a magnitude fainter visually and — like the nuclei of certain other planetaries — it may be variable in light.

Monitoring the nuclear region of the Ring Nebula for variations in visibility of this object is an excellent project for the well-equipped amateur. Nights having both good seeing and high transparency should be sought out in attempts to see it. Also the eyes must be well dark-adapted and averted vision is essential. A 12th magnitude star just outside the eastern edge of the nebula should be readily visible before attempting the much fainter central one.

The sight of this slowly expanding stellar remanant drifting silently through the eyepiece field on a warm summer night is one never to be forgotten. To see it is to sense true celestial glory.







Above: The "double-double" system of Epsilon Lyrae is a fascinating sight even in small telescopes. All four components appear white or only slightly colored. Above right: The unusual eclipsing binary Beta Lyrae is also an attractive multiple system with three dimmer companions arranged in a triangle around the variable primary. Drawings by James Mullaney. Right: The ghostly ring of the planetary nebula M-57 can be viewed easily with a small telescope, making this one of the most popular of all deep-sky objects. Photo by Steve Reed.

M-56

We conclude our survey of Lyra's wonders with a final stop approximately midway between Gamma (γ) Lyrae and Albireo (Beta [β] Cygni). Here, nestled in a dense stellar forest, is the remote cluster of suns known as M-56. Having the combined light of an 8th magnitude star and measuring some 3 minutes in diameter, this globular cluster is easily swept up in a 3 or 4-inch telescope at 45 power on a dark night.

Closer inspection at higher magnification — especially in 6-inch and larger scopes — reveals a granular texture in M-56 which is the precursor of actual resolution. The eye is seeing clumps of unresolved stars within the cluster itself; in moments of steady air and with averted vision, individual stellar pinpoints can be glimpsed at the edge of this starry ball.

Burnham's description of M-56 mentions that "William Herschel in 1784 resolved it into a mass of 11th to 14th magnitude stars; modern observers will find it readily resolvable around the edges with a good 6-inch mirror; the central mass requires a somewhat larger aperture...The field is richly sprinkled with vast numbers of faint and distant stars." Webb called it "faintish, perhaps resolvable in 3.7-inch; in fine field and rich region," and Smyth "a globular cluster in a splendid field." Curiously, Barns logged this object as a "semi-globular cluster," adding "neighborhood radiant."

Muirden described M-56 as "a globular cluster, unresolved in a small telescope but bright, with a curious 'V' of 7th magnitude stars north following." Mallas found this swarm "an impressive object. In the 4-inch refractor, M-56 is a bright, nearly circular glow, in which a few individual stars are seen. Unlike most other globulars, this one has no bright core."

Although no match for M-13 and the other big summer globulars, M-56 has an attractive appearance about it that brings the observer back time and again for another look. The rich stratum of stars through which we view it — some 45,000 light-years distant in the outer halo of our Milky Way Galaxy — certainly has something to do with its appeal. Why not have a look at this star-studded globe with your telescope the next dark clear night and see for yourself?

Considering the many wonders to be found in even a small sky area like that of Lyra, we are compelled to agree with R.M. Jones' inspired belief that "it is not accident that wherever we point the telescope we see beauty...."

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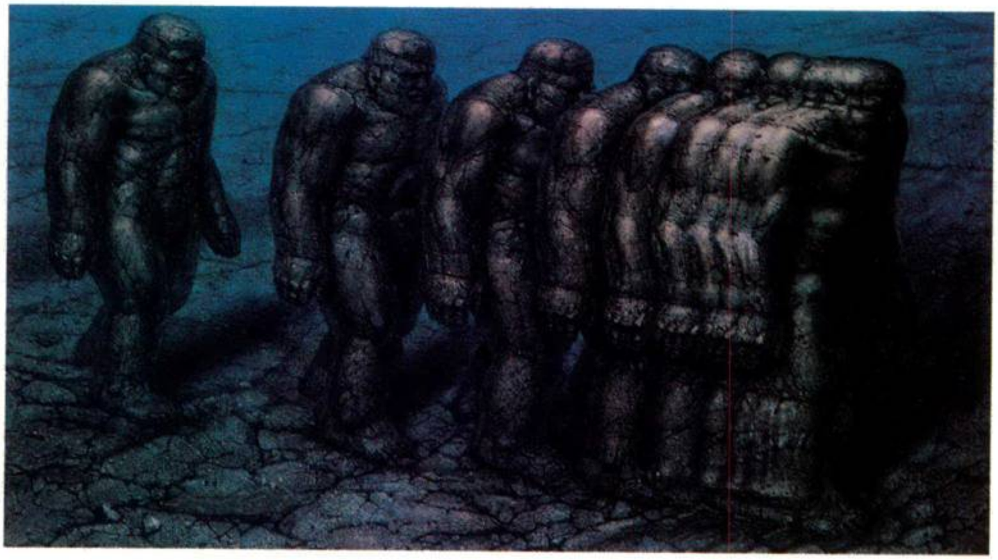

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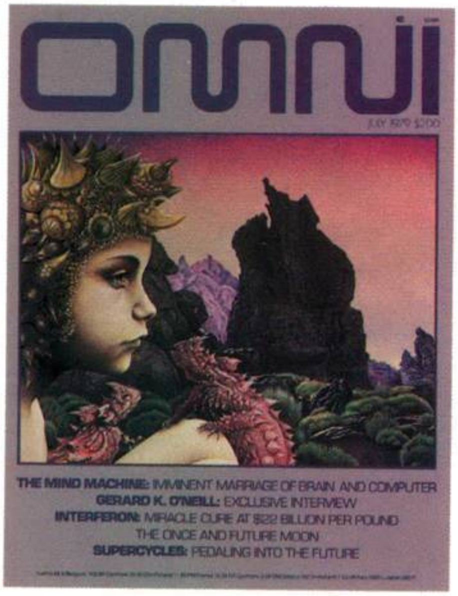
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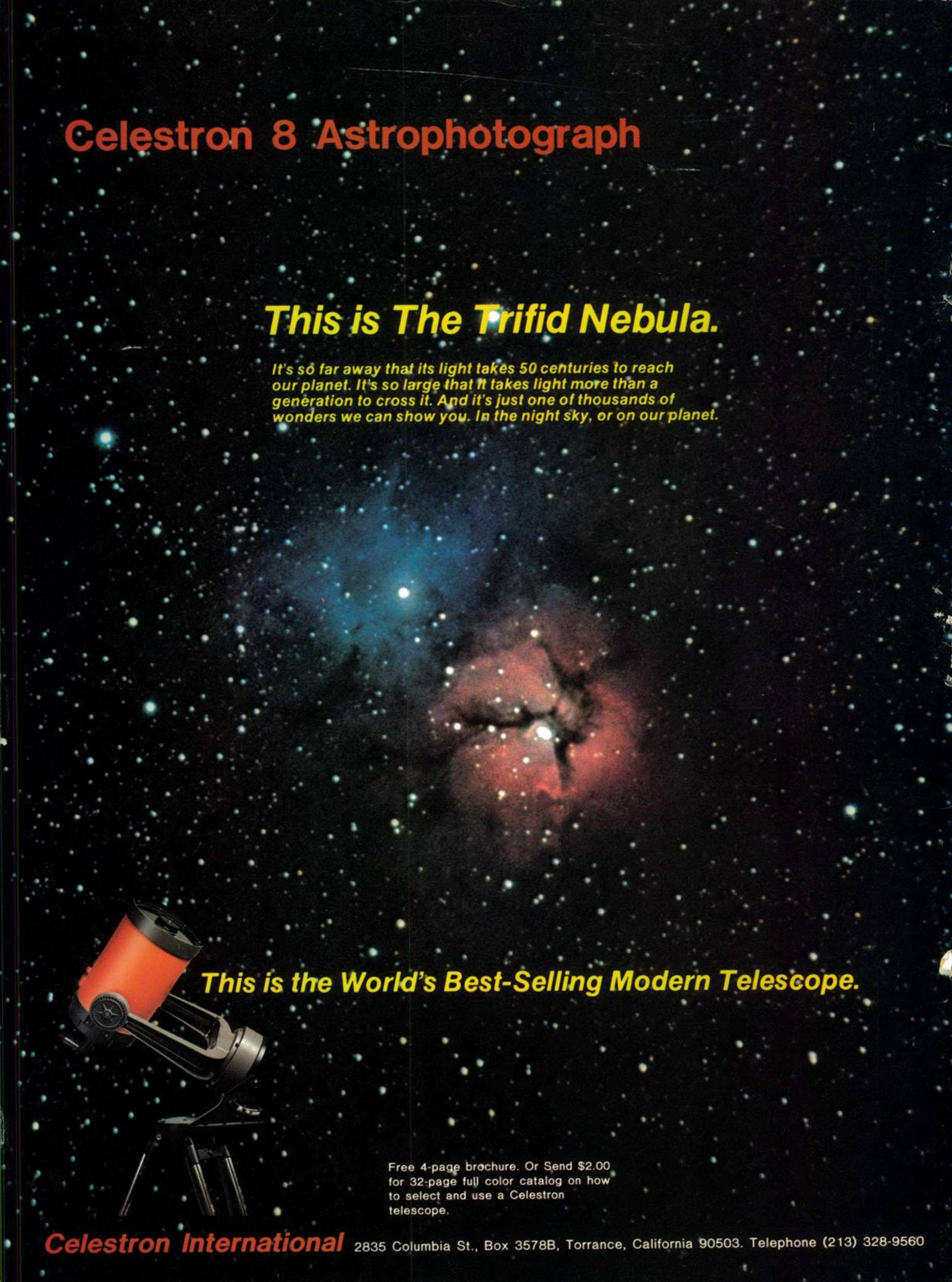

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